SUNLIGHT AND THE USE OF HOLOGRAPHIC DIFFRACTION GRATING: An Environmental Perspective

by

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ABSTRACT

The movement of sunlight within a building establishes a temporal relation to the spatial structure. Early civilizations aligned buildings with the sun to designate specific calendar days. Gothic and Renaissance cathedrals employed the transient movement of sunlight to activate the interiors with continually varying qualities of light.

Light illuminates surfaces, but it is also a material with specific, perceivable qualities. Holographic materials diffract light. Focalpoint, a water fountain installation, incorporated holographic diffraction grating to diffract and focus sunlight as an environmental installation which distinguished the sun's temporal progression with color variations throughout the day.

Holographic diffraction grating is a material with the potential to integrate solar energy and architectural design concerns through the focused projection of color into an environment.

Thesis Supervisor: Otto Piene
Title: Professor of Visual Design

ACKNOWLEDGEMENTS

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I. SANCTITY AND SUNLIGHT

"Awe, you see, is what moves us forward."

(Joseph Campbell)

The sun rises in the east, sets in the west and is higher in the sky at noon in the summer than in the winter. We assume this as casually as we acknowledge the changing seasons. Early cultures assumed nothing. They observed the sun's course during the year carefully distinguishing its relation to seasons and other celestial events. They recognized the yearly calendar by the recurrence and placement of noted events. They carefully aligned markers or structures to designate these events exactly. Early cultures knew the progression of the zodiac which marks the sun's slow march through the solar system. They interpreted the sun's movement through the zodiac as celestial dynasties overthrowing the old order with the new. They navigated by the stars and bestowed the secret knowledge to the initiates by revealing the stellar corollaries of their mythologies.

Celestial events were deified as creator, protectors and destroyers of life. Mircea Eliade alleges that early cultures "live in a sacralized cosmos," in which a totality exists between human, animal and vegetable worlds.[1] These cultures were bound to the natural cycles of the world and recognized their subtleties. Sunlight was considered sacred in both Egyptian and Mesoamerican cultures. By predicting its seasonal passage, they determined the proper time to plant and harvest. Monuments built to distinguish the sun's passage were the environmental art of the day. These structures calibrated the seasonal calendar and honored the deity with their splendor.

Later cultures of the Gothic and Renaissance periods interpreted sunlight metaphorically as divine light. Their structures did not delineate the sun's temporal cycle, but manipulated the elusive, dramatic qualities of light to create an ethereal environment. Sunlight intensified an experience through its controlled use and bound the culture together through its sacred implications.

II. TEMPORAL AND TRANSIENT SUNLIGHTING

"Buildings are time related; they were planned for and served a specific use."

(Horst Hartung)

Early civilizations relied on the celestial calendar for survival. They watched the passage of the sun, moon, and stars to calculate seasonal changes which formed the basis of much of their mythology. The sun's passage across the sky during the year shifts in respect to the seasons. This passage is called the "path of the ecliptic." By observing the sun's rising and setting points, early astronomers noted the sun's passage along the ecliptic. They knew that the northern and southern extremes were the solstices. Midway between these extremes is the day of the equinox. Thus, on the day of summer solstice, the sun rises at its highest northeastern position on the horizon and sets at a point furthest to the northwest. At winter solstice, the shortest day in the Northern Hemisphere, the sun rises at its south-eastern extreme and sets furthest to the southwest.

Early astronomers placed horizon markers in alignment with the point were the sun met the horizon. They watched from a particular position or building until the sun was seen on the horizon in conjunction with the marker. This distinguished the particular day precisely and is known as horizon based astronomy. A few cultures oriented buildings to allow the sunlight to enter them and illuminate a room on the specific day. The Temple of Amen-Ra in Karnak, Egypt is an example of this type of orientation.

The Temple of Amen-Ra was dedicated to the sun. The original sanctuary, Ipet Sont, was constructed in 2000 B.C. and expanded throughout the centuries. In 1480 B.C., Thutmose III erected the Hall of Festivals at the Temple's eastern extreme blocking the continuous corridor through the complex. The Temple of Amen-Ra is oriented southeast to northwest and faces the Nile River. In 1894 Sir Norman Lockyer published The Dawn of Astronomy and presented the theory that the Temple of Amen-Ra was aligned with the summer solstice sunset. He speculated that the 547 meter hallway through the complex with its series of door frames collimated the setting sunlight, reducing it to a narrow, evenly illuminating beam (fig. 1). When this beam fell on the inner sanctuary, Lockyer believed that it flashed brilliantly on the back wall of the Hall of Festivals.

In 1973, Gerald Hawkins, author of Stonehenge Decoded, visited the Temple of Amen-Ra, recalculated the axial alignment and found it to be 116.90 degrees east of north which "was the position of the sun on its southern extreme at winter solstice during the epoch of Hatshepsut and Thutmose, between the years 2000 and 1000 B.C."[2]

A report in 1891 maintained that the summer solstice sunset was blocked from entering the Temple by the Theban Hills on the Nile's West Bank. Hawkins proposed that the Temple of Amen-Ra was oriented towards the winter solstice sunrise from the eastern end of the temple, although the entrance to the inner sanctuary was blocked by the Hall of Festivals (fig. 2). Further surveying revealed that an upper story room called the "High Room of the Sun" was also aligned with winter solstice sunrise. This room was constructed during the reign of Thutmose III and dedicated to Ra-Hor-Akhty, the god of the rising sun (fig. 3). Hawkins believed that the alignment of this room towards the winter solstice sunrise corresponded to Egyptian myths that on the day of the winter solstice, the sun reached its "turning point" or "place of combat" with darkness which it must overcome each year so that "the new (sun) god is born free in victory at dawn on mid-winter's day."[3]

The orientation of the Temple of Amen-Ra demonstrated a religious function integrating the solstice calendar with the ancient Egyptian beliefs in the annual reincarnation of the sun. The Egyptian temple of Abu Simbel was erected to commemorate another specific event. Ramses II built Abu Simbel as a celebratory monument to his thirtieth jubilee year as pharaoh. The megalithic structure was hewn from cliffs on the banks of the Nile. It was aligned with the October 18th sunrise in 1260 B.C., the first calendar day of Ramses' jubilee year. The rising sun's rays penetrated the interior 60 meter passage illuminating statues of Ramses II and the supporting gods. Hawkins suggests "that the flash of sunlight striking the pharaoh god statue was believed to bring life and rebirth to Ramses starting a process of deification" (fig. 4).

Though horizon based astronomy was employed by the Mayan cultures of Mesoamerica, they also observed the zenith passage of the sun. On that day, the sun traversed directly overhead casting no shadow at midday and forecast the seasonal shift in the tropics from wet to dry. This marked the beginning of the planting or harvesting season. Anthony Aveni and Horst Hartung, astronomers working in Mesoamerican archeology, maintain that the people of Monte Alban, a religious compound on a plateau near Oaxaca, Mexico, recognized the day of the sun's zenith passage by a twofold method. Building J, built within the rectangular central plaza, has a unique arrow-shaped plan and is oriented 47 and 1/2 degrees east of astronomical north. This position points towards the horizon where Capella, the sixth brightest star in the sky "underwent heliacal rising precisely on the same day as the first annual passage of the sun across the zenith of Monte Alban."[5] A star rises heliacally when it appears over the horizon in the dawn sky just before sunrise. Thus, the astronomers at Monte Alban were alerted to the sun's zenith passage by the early morning appearance of Capella. Aveni measured a perpendicular from the northeast face of Building J which cut through the center of the staircase of Building P on the east side of the plaza. Halfway up this staircase, the entrance to a chamber was discovered which contained a narrow, vertical shaft open to the sky. Aveni thought that this shaft was a siting tube which the sun would fill at noon on its zenith passage[6] (fig. 5).

The Mayans, like the Egyptians, considered the sun to be a major deity who died and was reborn both daily and yearly. The sun's zenith passage was thus a day of importance to the Mayan agricultural and religious calendar, being the day that the sun climbed highest into the sky while forecasting the coming change of season.

To the north in Chaco Canyon, New Mexico, the Anaszi culture established a large trading and distribution center between 950 and 1150 A.D. Pueblo Bonito, a D-shaped, multi-storied pueblo is suspected to have housed five hundred to one thousand people. Pueblo Bonito is oriented along an "east-west axis so the straight back of the D forms a high wall along the north side."[7] The south, semi-circular face was oriented to allow for maximum sunlighting during the year (fig. 6). The Anaszi held their events in kivas, circular ceremonial rooms sunk into the ground and covered with a roof. The largest kiva at Pueblo Bonito, Casa Riconada, has post holes for roof supports set at the cardinal points and niches built into its walls which possibly were illuminated by sun-light on specific days. Jonathan Reyman of Southern Illinois University suggested that bonfires might have marked the solstice sunrise and sunset points along the surrounding mesa tops which could have been seen from within Casa Riconada.[8] Reyman located pottery adjacent to burned areas located on the mesa in the direction of winter solstice sunrise and sunset. This pottery dated from approximately 1100 A.D., contemporary with Casa Riconada. Other evidence has shown that bonfires were employed as signals between the pueblos of Chaco Canyon.[9]

In Egyptian and Mayan cultures, only the priest and rulers had access to the sacred buildings. The kivas, however, were interior spaces intended for the religious or ceremonial meetings of clan groups or the entire community, as was the case with Casa Riconada. This public use of religious buildings is also observed in European cathedrals. Most Christian churches were oriented towards the east, but occasionally former foundations or earlier sacred sites predetermined the church's position.

St. Peter's Basilica in Rome is aligned with its apse towards the west. Lockyer maintained that

> in regards to old St. Peter's at Rome, we read that so exactly due east and west was the Basilica that, on vernal equinox, the great doors of the porch of the quadriporticus were thrown open at sunrise, and also the eastern doors of the church itself, so as the sun rose, its rays passed through the outer doors, then through the inner doors, and, penetrating straight through the nave, illuminated the High Altar.[10]

Old St. Peter's was built in the early 4th century A.D. by Constantine, the first Christian emperor of the Roman empire. According to legend, the Basilica was built to commemorate Constantine's vision of a shining cross in the sky on the eve of a battle near Pons Mivius on October 28th, 312.[11] He ordered his soldiers to inscribe the sign on their shields and proclaimed that if victorious, he would convert to Christianity and build a church. It is probable that the glowing cross in the sky was generated by the low rays of the setting sun refracting off ice particles into horizontal and vertical beams with the sun at their center.

> On October 27th, 312 at Rome sunset was at 17,18 h. in the west-south-westerly direction. Being on the right bank of the River, north of the city, Constantine's army must have seen the phenomenon of W.S.W. (before sunset), that is, in the sky over the city not much above the site of St. Peter's.[12]

It is speculated that the political support from the growing Christian population was an additional motivation for Constantine's conversion to Christianity and building a church commemorating a vision and a military victory.[13] The Basilica was erected over a Roman necropolis and adjacent to an ancient circus from the time of Nero (fig. 7). The necropolis was believed to contain the tomb of St. Peter, martyred on an inverted cross. Other excavations under St. Peter's revealed tombs aligned on the east-west axis (fig. 8). The orientation of the previous necropolis could have determined the Basilica's alignment. However, the Easter season traditionally falls near the vernal equinox and would have been an appropriate date to honor in the Christian church.

The present Basilica, rebuilt over Constantine's in the 16th century, maintains the original alignment. The centralized plan initiated by Bramante and completed by Michelangelo, was designed as a majestic environment, honoring the tomb of St. Peter and the Holy See of Papal power. Similarly, medieval cathedrals in Europe were built by rival bishops to distinguish their individual sees.

Chartres, an early Gothic cathedral dedicated to Mary, became a famous shrine attracting pilgrims to view the sacred mantle of the Virgin, Chartres' most treasured relic. Oriented with its apse easterly, Chartres was originally built over a grotto believed to be the center of a Druid cult to "a virgin who was to conceive."[14] Through the centuries, the church was rebuilt repeatedly after fires. In 1194, a fire destroyed all of the previous structure except the stone crypt and West Portal. The recovery of the sacred mantle provoked a massive public effort and Chartres Cathedral was built by 1220.

The 12th century stained glass in Chartres is some of the finest ever produced. It is known for its intricacy of design and color saturation. To the Medieval mind, physical light was analogous to divine light. The interior of Chartres Cathedral is bathed in a blue glow. It was designed to be an ethereal environment, distinct from the exterior world. Viollet-le-Duc stated in his treatise on the northern lancet of the Tree of Jesse that "the blue is the light in windows, and light has value only by opposition. Blue is that luminous color which gives value to all others."[15]

Like St. Peter's Basilica, the sun proceeds around Chartres Cathedral illuminating the interior throughout the day. Sunlight is transient, casting light onto the interior architectural forms and migrating across them. The interior of St. Peter's Basilica is illuminated with natural sunlight, while in Chartres Cathedral the passage of sunlight is transformed into the movement of colors. Both environments employed sunlight as a transcendent religious symbol. Likewise, the early Egyptian and American cultures recognized the metaphoric content of sunlight, implying that the sun god lit the interior of the temple only on the sacred day. Sunlight in these early cultures designated time integrating religion with the seasonal calendar.

Today, physics maintains that light is composed of both particles and waves. Sunlight illuminates our structures defining planes, textures and volumes. It is a utilitarian commodity frequently employed but often devoid of its previous temporal and metaphysical associations. Nevertheless, the sun continues its yearly progression between the solstices, rising and setting daily.

The movement of sunlight across architectural interiors delineates the sun's daily and yearly passage. Light and shadow distinguish this movement, but the correlation to the sun's annual cycle is rarely perceived by the casual observer. The transient colored light illuminating the interior of Chartres Cathedral differentiates the daily and seasonal passage of the sun.

> The sensuous power of the luminous tones of Chartres glass, which waxes and wanes in strength as the day proceeds, grows at dusk, when the windows seem to glide loose from the framework of the cathedral architecture and appear like colour floating in space.[16]

The movement of color across architectural forms is distinct and easily distinguished. The colored light attracts us. Its purity can provoke a brief sense of timelessness, leaving us momentarily speechless, absorbed in the sensation.

Holography is a contemporary method to work with color directly. Illuminated by sunlight, a hologram projects colors of light. These colors vary with the sun's angle. Their intensity and purity compares only to the sunlight from which they are derived. The movement of these colors through an environment delineates the passage of time through space as the colors migrate across the architecture in varying hues thus reintegrating an awareness of the sun's temporal passage with its effect on an interior environment.

II. ILLUSTRATIONS

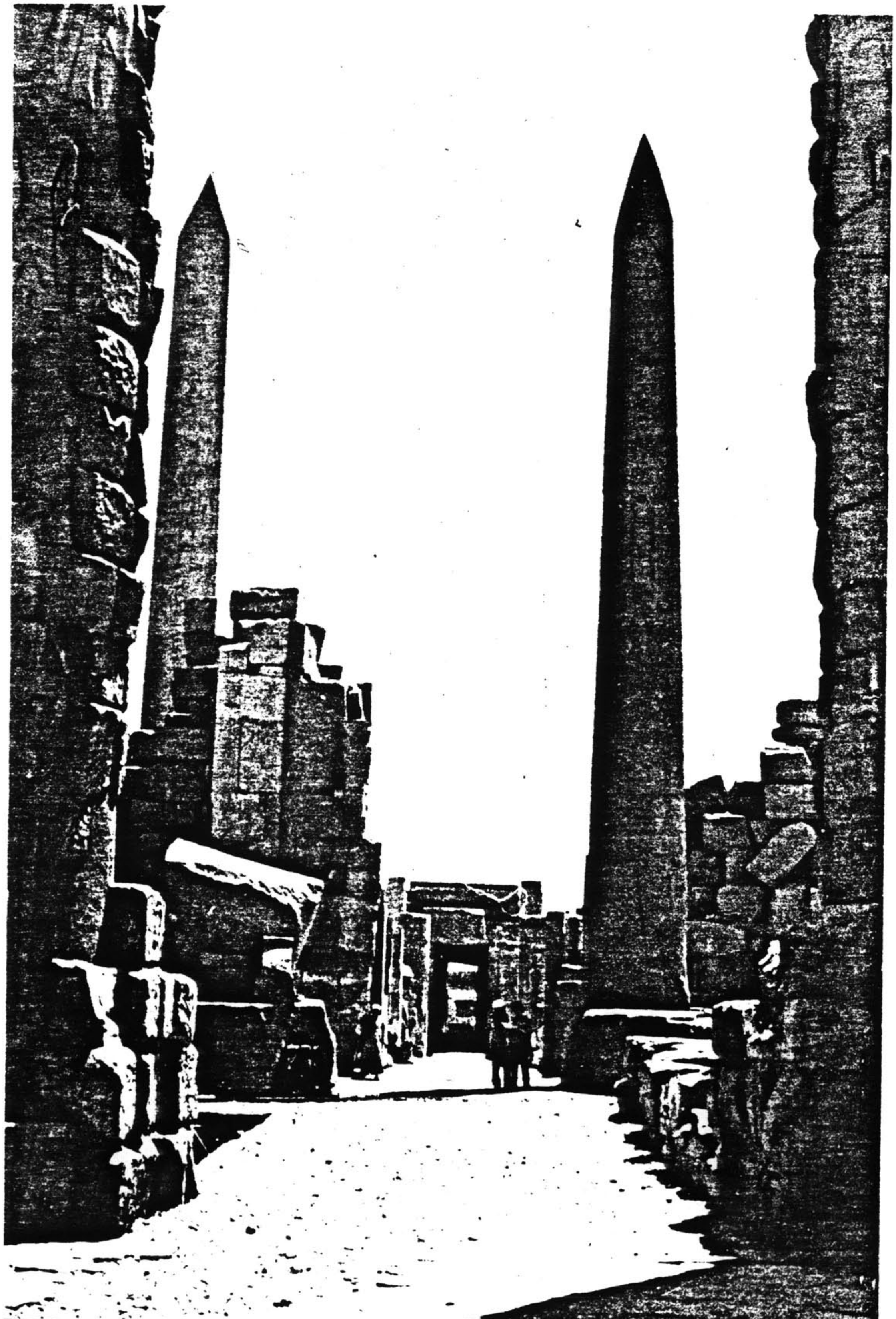


fig. 1 Central corridor through the Temple of Amen-Ra, Karnak, Egypt

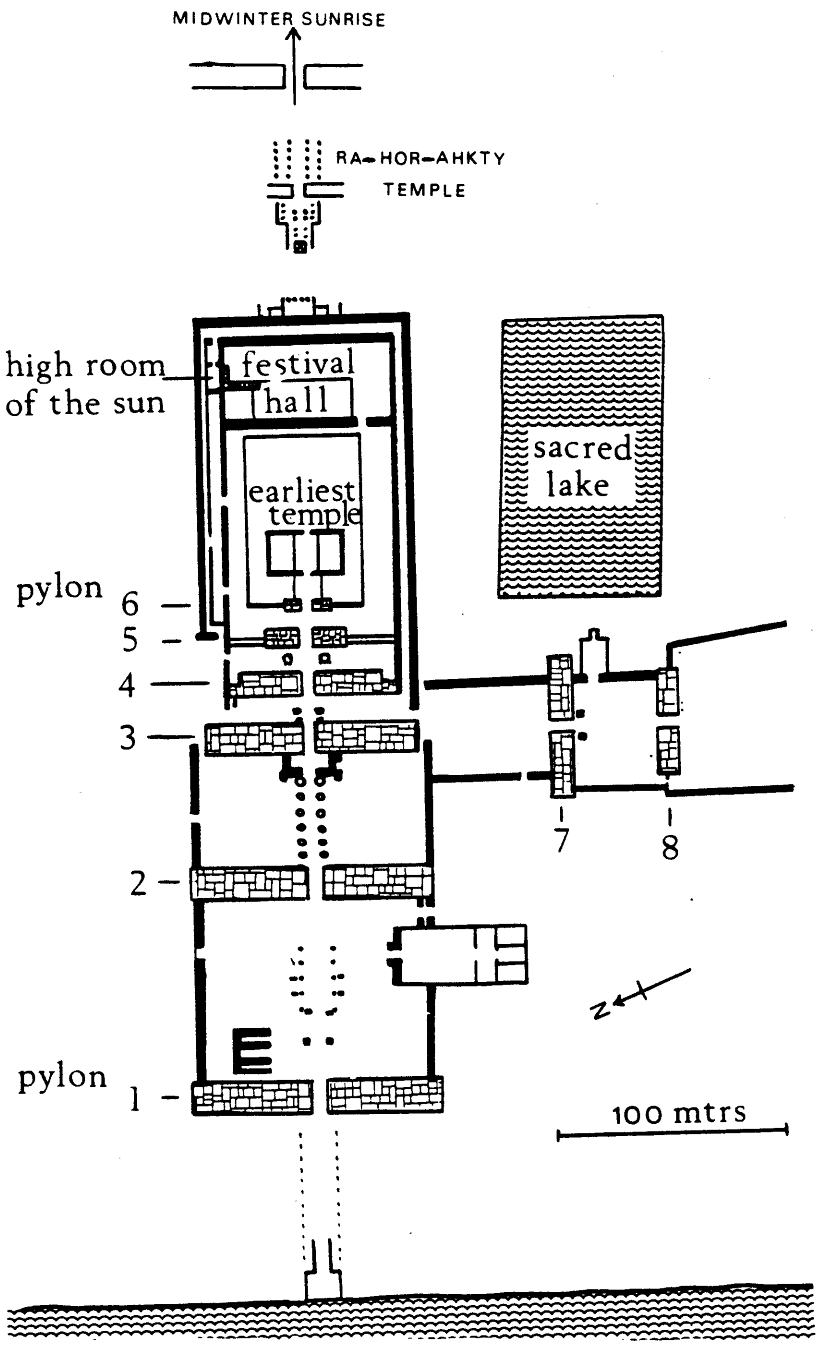


fig. 2 Plan of the Temple of Amen-Ra

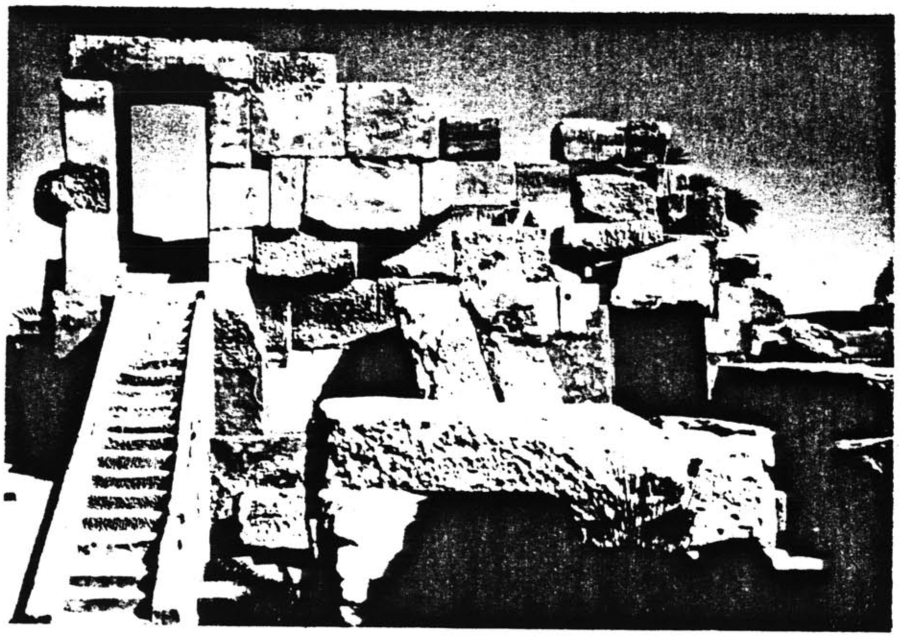


fig. 3A Staircase leading to the "High Room of the Sun"

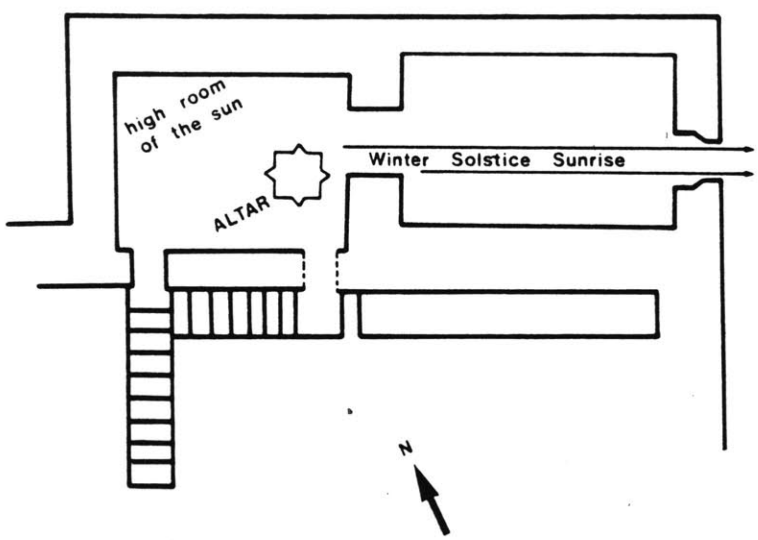


fig. 3B Plan of the "High Room of the Sun"

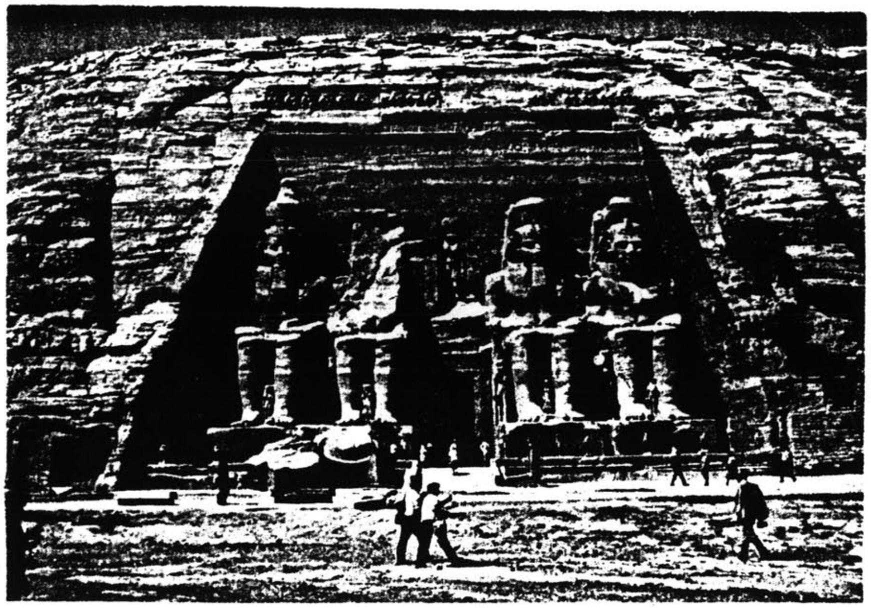


fig. 4A Facade of the Temple of
Abu Simbel

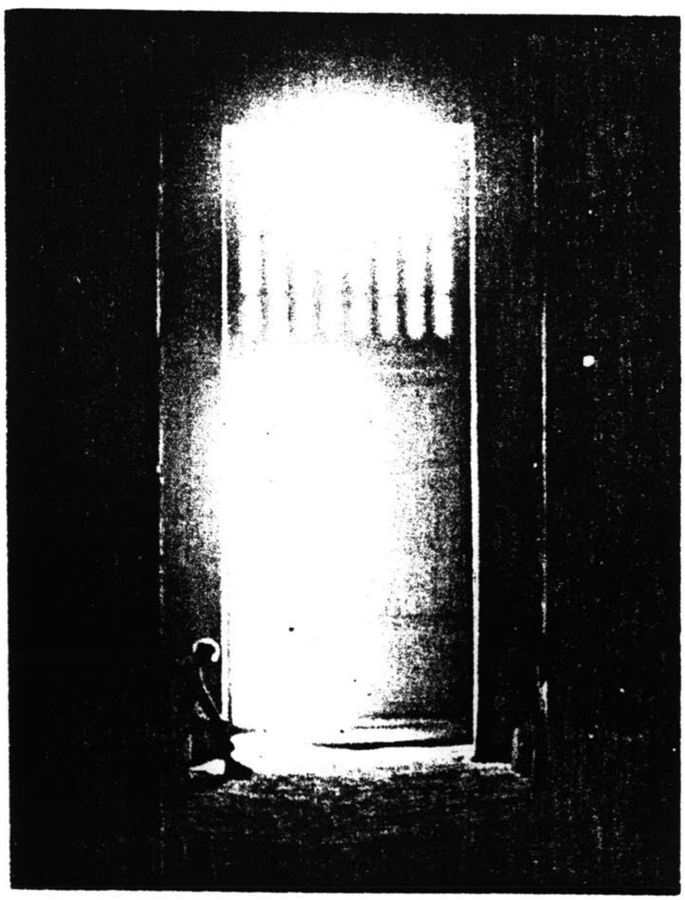


fig. 4B Sunlight entering the
interior of Abu Simbel

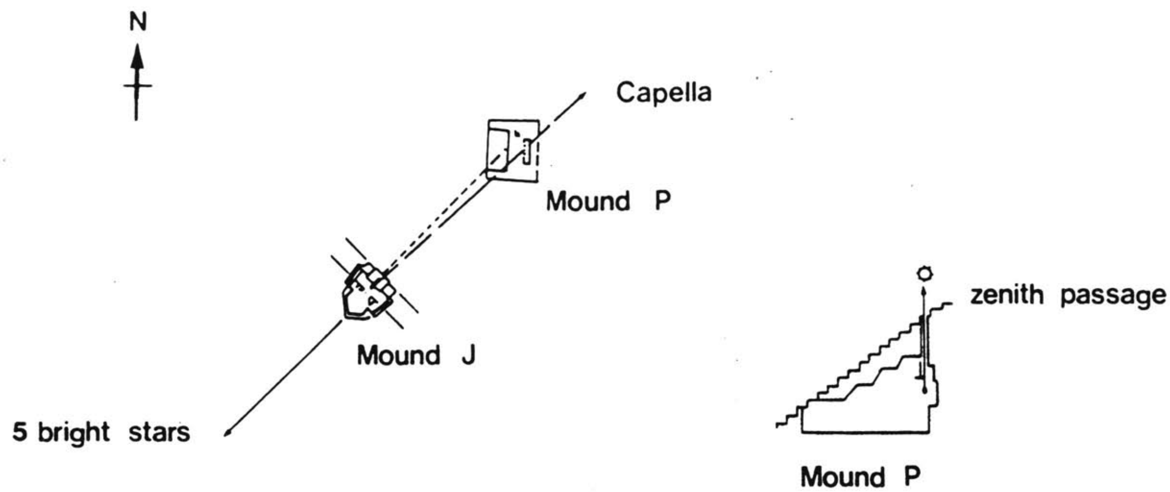


fig. 5A Plan and elevation of Building J and Building P, Monte Alban

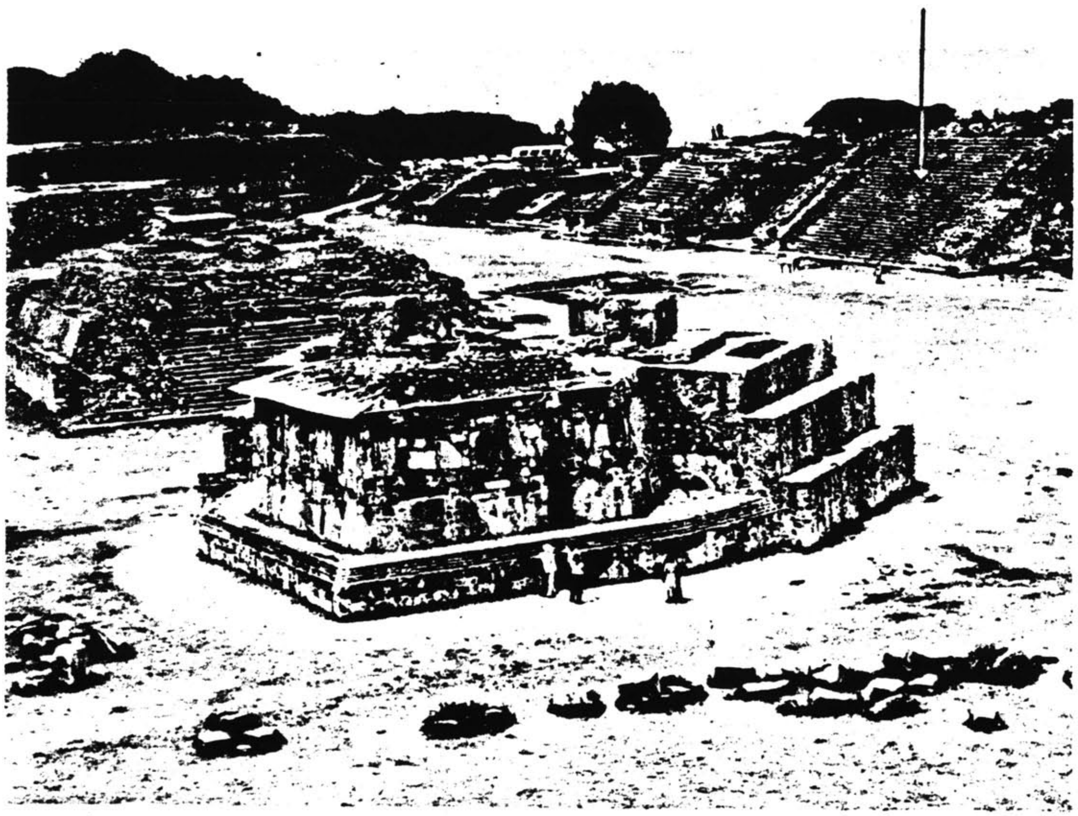


fig. 5B Building J (foreground) and Building P across the plaza. An arrow indicates the entrance to the internal chamber in the staircase of Building P.

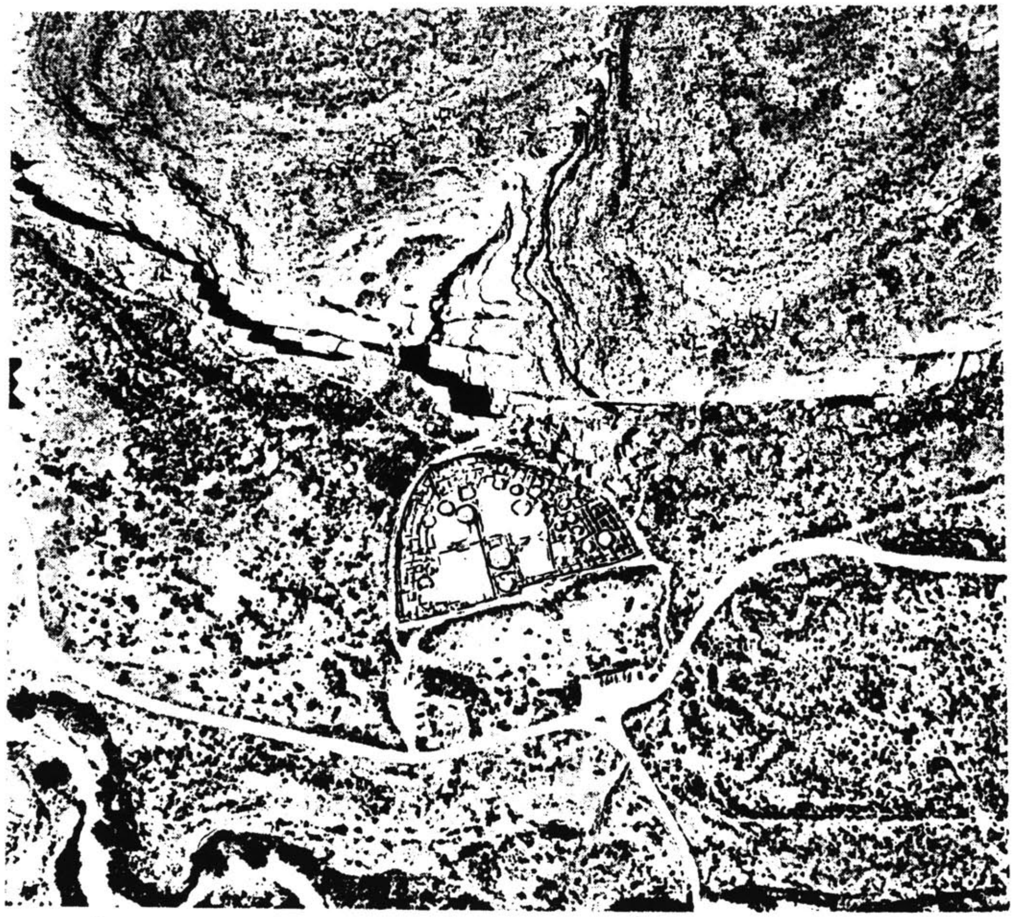


fig. 6 Aerial view of Pueblo Bonito

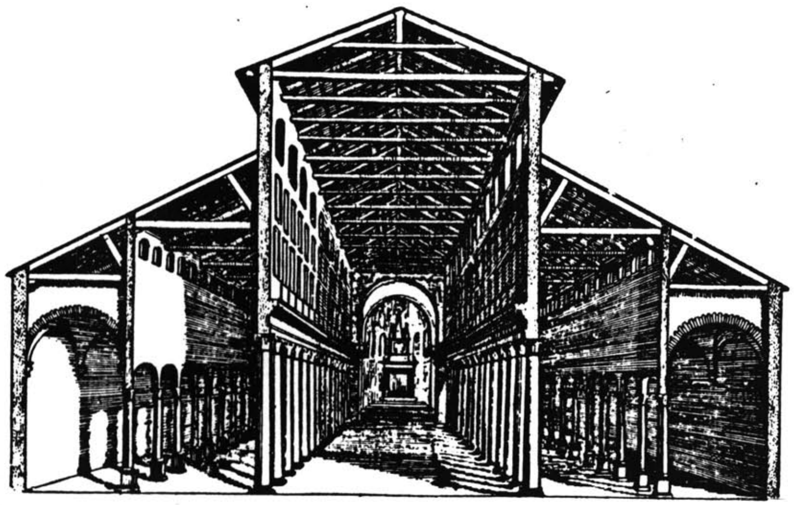
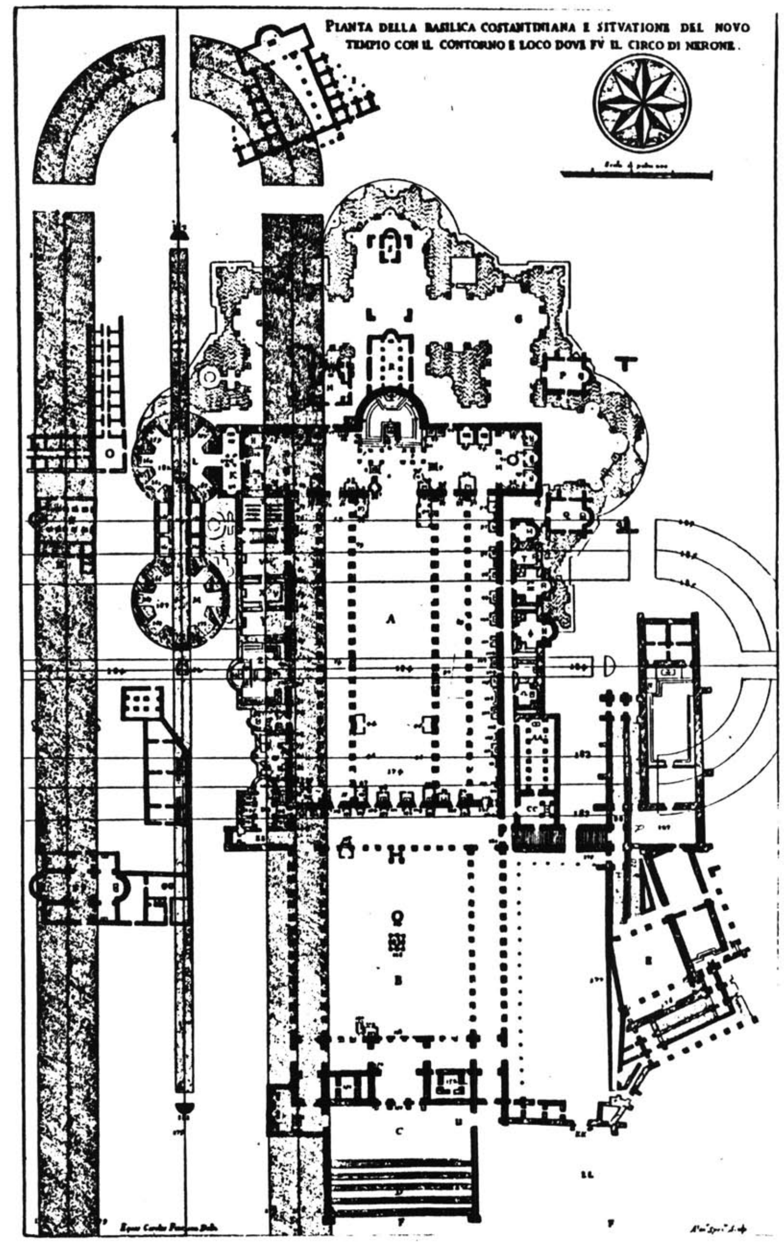


fig. 7A Elevation of St. Peter's

fig. 7B Plan showing old St. Peter's (center, dark line), the present Basilica (lighter tone), and the adjacent foundation of the Roman circus (oblong track on the left).



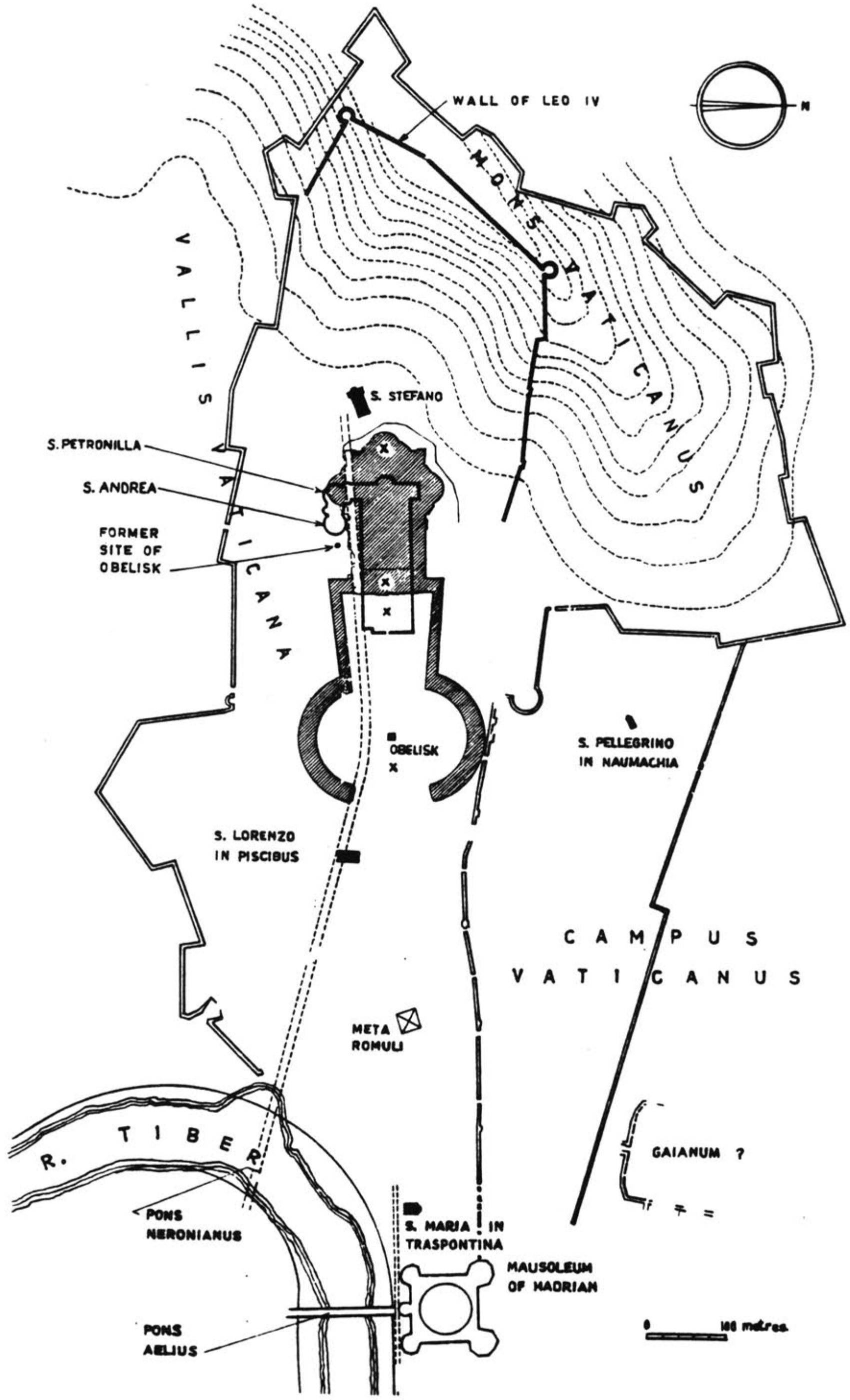


fig. 8 Plan of the Vatican area showing the orientation of Old St. Peter's (black line), the present Basilica (hatched), and excavated tombs ("X" marks) on the east-west axis.

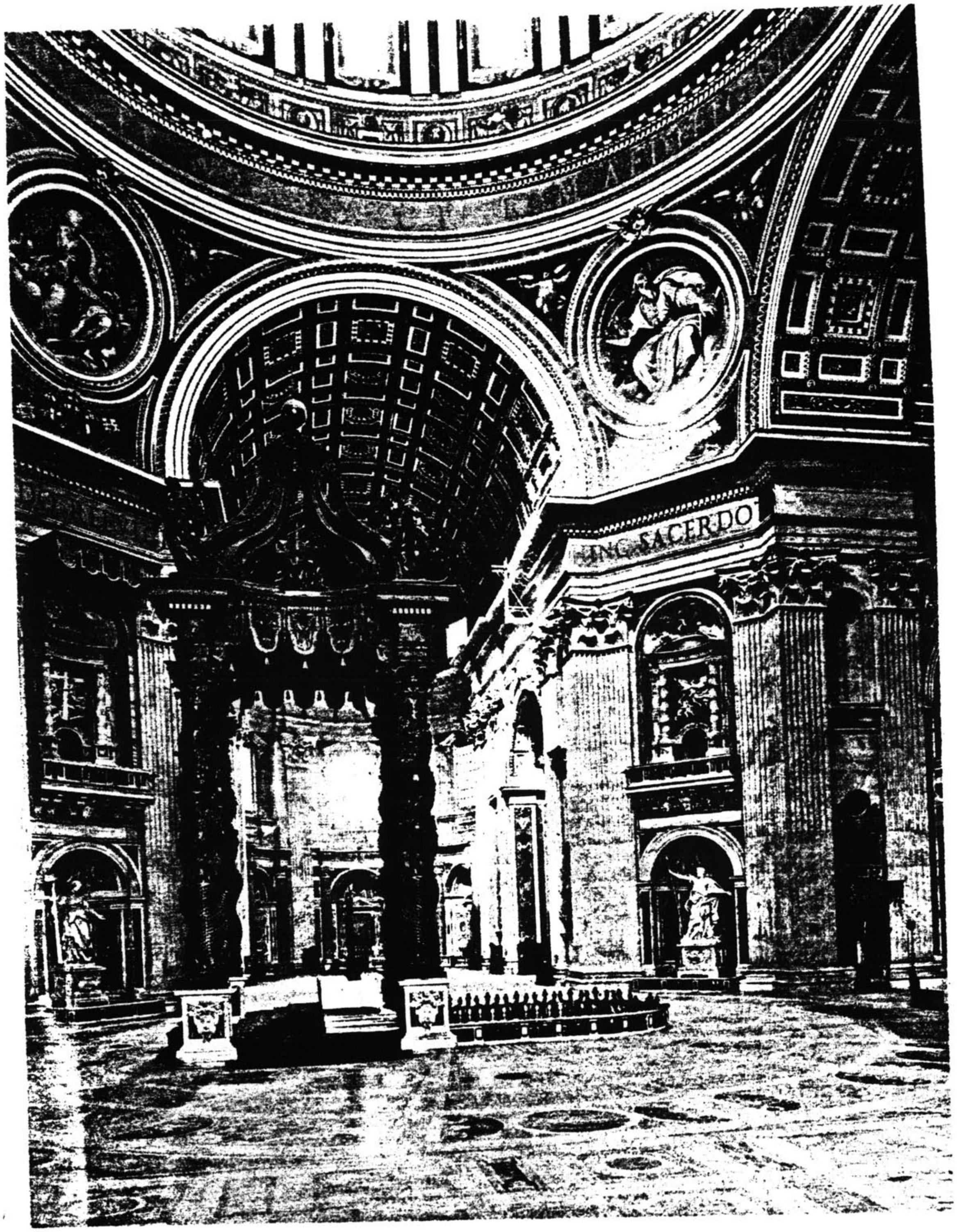


fig. 9 Interior of St. Peter's Basilica, Rome
(Nave and South transept)

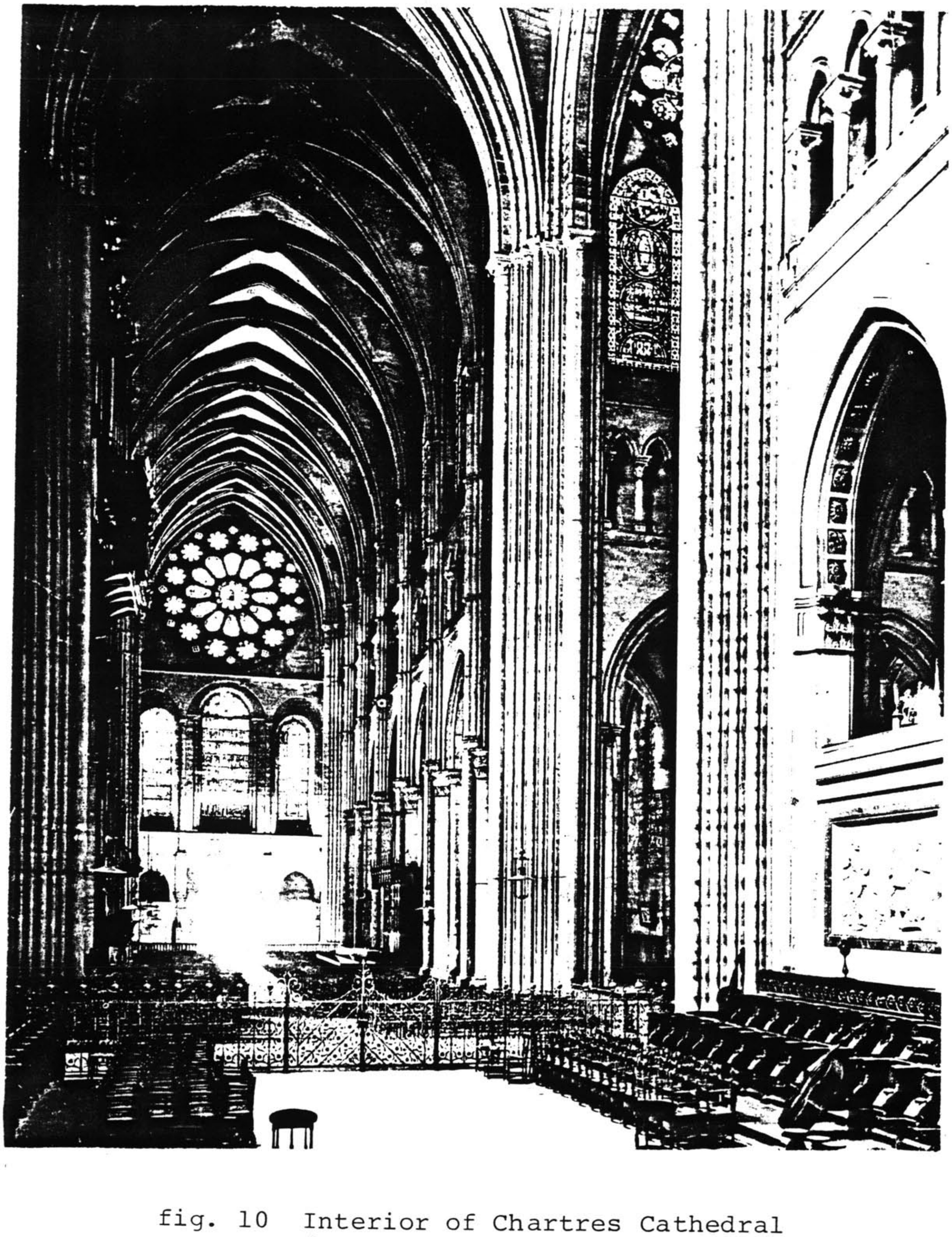


fig. 10 Interior of Chartres Cathedral
(Nave and South transept)

III. FOCALPOINT

"The most difficult medium of
all to work with, because it
is intangible, light is the
only material which can shape
space without replacing it.
It can fill without filling."

(Abe H. Feder)

Focalpoint was a holographic water fountain installation exhibited in the atrium of the Whitaker Medical Science Building at MIT for six weeks from November 8th to December 16th, 1982 (fig. 11). Focalpoint developed from my fascination with color and desire to work with sunlight. I was intrigued at the prospect of projecting pure colors and focusing them in space. Pure color is derived from light. It is a material with unique properties. Laser light combines exquisite pure color with a sparkling, slightly three-dimensional texture called 'laser speckle.' I wanted to transform sunlight into a tangible material apparent by its color saturation, intense luminosity and three-dimensionality. I intended the viewer to perceive the sheer potency of pure colors in space.

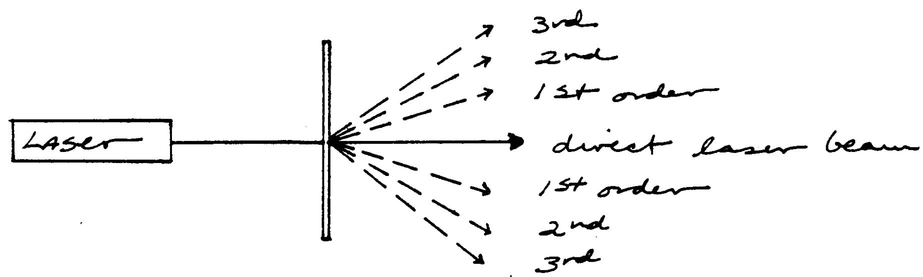
Focalpoint, as a water fountain, developed from technical solutions to the inherent holographic limitations. Holographic diffraction grating splits the sunlight into its spectral colors. The sun's angle alters the color and presence of the installation varying it from vibrant to subtle. Water lensed the sunlight, increasing the holograms' limited viewing angle while enhancing the sculpture with its patterns of motion and sound. These transitions of color and sound enabled Focalpoint to interact with the atrium's environment.

Focalpoint evolved from a series of light projects. I began by manipulating laser light. Using an argon-krypton laser which emits a green beam, I placed transparent materials and optical elements in the beam to create an environmental light composition by splitting, spreading and diffracting the light. Diffraction separated the laser light into its component colors. Diffracting the argon-krypton beam produced six lines of saturated colors including indigo, blue, turquoise, green, yellow and red. Lenses expanded the beams casting laser light onto the floor, wall and ceiling surfaces. Controlling the textural qualities and light intensities enabled me to transform an interior with color. However, the installation lacked the movement of light, necessary to create subtle transitions in both form and color.

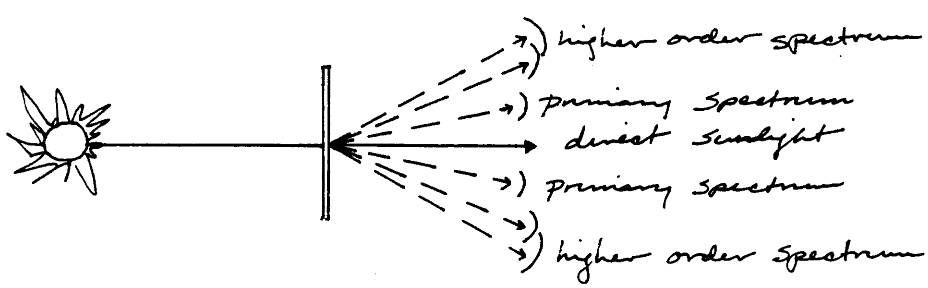
The sun is transient. Illuminating a hologram with sunlight would gradually alter the colors perceived throughout the day. Holographic images can be seen in front of the plate as a "real image" or as a "virtual image" behind the plate. Using sunlight to illuminate holographic diffraction grating, the sun's spectral colors could be projected as real holographic images changing color in response to the sun's angle.

Holographic diffraction grating is made by exposing holographic film to a laser. The laser beam is split by a partially reflective and transmissive beamsplitter. The beams are expanded through lenses and reconverged on the holographic emulsion. The emulsion records the interference pattern of the light waves; the pattern created by the interfering beams as they intersect. The developing and bleaching processes remove the exposed silver halide and create an undulating emulsion surface which diffracts light into a series of angles.

When a helium-neon laser beam diffracts through a holographic diffraction grating, it produces a series of red dots. The two dots of light adjacent to the direct beam are called the first order of diffraction. The next set of dots are the secondary orders, the third is the tertiary, etc. Often the orders beyond the primary are referred to as the higher orders of diffraction:



When sunlight diffracts through a holographic diffraction grating, a series of rainbows are evident. The primary order spectra are the brightest. Rainbows seen in the sky are formed from sunlight diffracting through moisture in the atmosphere into a first order spectrum. Due to the proximity of the higher orders, their spectra overlap producing a continuous band of mixed colors which gradually fade the higher the order:



Lightscape was a sculptural installation using holographic diffraction grating to project the sun's primary spectrum. Composed of four plexiglas units, each 8' long by 22" at maximum height, each unit was mechanically fastened and held nine 10" square sheets of holographic diffraction grating.

Lightscape was originally installed in front of Kresge Auditorium at MIT (fig. 12). The crescent-shaped units were designed to echo the contours of Kresge while maximizing the efficiency of the gratings. The curved structures were illuminated throughout the day as the sun passed in an arc over the site. The shape of the structures also increased the viewing angle by permitting wide lateral visibility.

Crossing Massachusetts Avenue, a deep blue was visible. Drawing closer, the blue became progressively lighter. Within twenty feet of the installation at midday, the four units appeared in four distinct colors: red, orange, green and blue. The colors were vivid, enticing the viewer to walk through the continuous sequence. The sun's passage during the day transformed the colors from blue-greens in the morning, through the spectral colors at midday, to soft blues during the late afternoon. Indirect light from an overcast or cloudy sky diffracted into subtle gradations of pastel colors which varied during the day.

The gratings were temporarily adhered to the unsealed plastic structures. The combined effect of ground moisture and sunlight created a humid atmosphere between the plastic causing specks of mold to grow on the emulsion surface.

Holographic emulsion like photographic emulsion is gelatin based. It absorbs moisture rapidly and is a fine culture for mold. The mold etched the emulsion surface permanently damaging the gratings and eventually ruining the installation.

Focalpoint developed from questions encountered in these projects. Primarily, I was enthralled by the uninterrupted sequence of higher order colors. Magenta is not apparent in the primary spectrum; neither are areas of yellow, pink or white. I wanted to focus the mixed colors of the higher order spectrum and realize a large-scale sequence of these colors in space. However, to prevent moisture damage, the gratings had to be sealed permanently. Glass plates coated with holographic emulsion could be laminated to another glass surface with optical cement. Unfortunately, the flat glass surface limits the viewing angle to a position directly in line with the illuminating source. This demanded optical alternatives to extend the viewing axis. Lightscape was exhibited outdoors. Focalpoint combined the extensive use of glass with an exhibition date during the unpredictable month of November. These practical considerations demanded an interior site. However, the gradual color transitions within interiors would reflect off architectural surfaces and create recognizable patterns of the sun's progression through space. Focalpoint was a technically demanding project which attempted to synthesize these concerns.

The final design of Focalpoint included four areas which I will outline in the following section:

1- the production of thirty holographic diffraction gratings to focus a single higher order spectrum in space

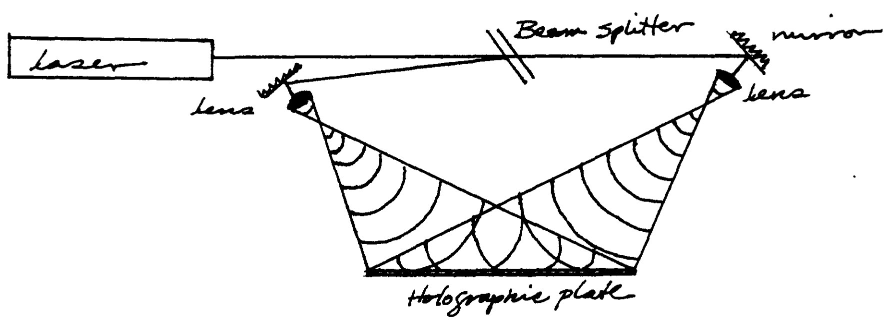
2- the permanent lamination of the thirty glass plates in three vertical rows of ten each to a safety glass panel

3- the use of ten 10' glass pipes as a combined optical and conduit system

4- the design and fabrication of the structural supports, base, and pump and manifold systems

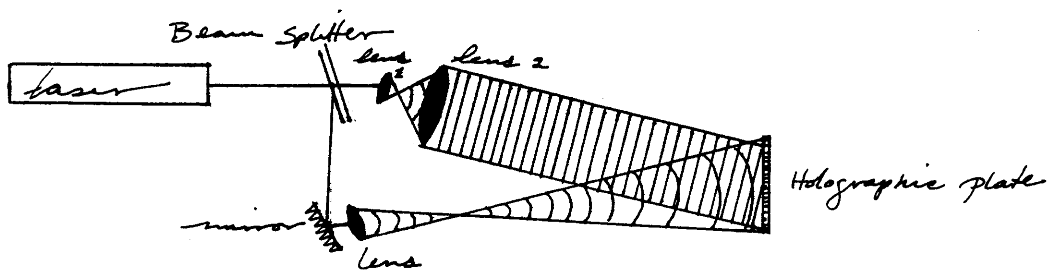
HOLOGRAPHIC DIFFRACTION GRATING

The holographic diffraction gratings in Focalpoint were holographic optical elements which focused light like a lens and diffracted it like a holographic grating. Each grating required two considerations: first, to diffract sunlight at specific angles producing the continuous higher order spectrum; second, to focus these colors as real images in front of the plate. Like the diffraction gratings in Lightscape, these holograms were exposed to two beams of laser light interfering on the emulsion surface. Lightscape projected colors but did not focus them. The colors diverged or spread as they travelled away from the sculptures. These gratings were made by interfering two spherical beams of light:

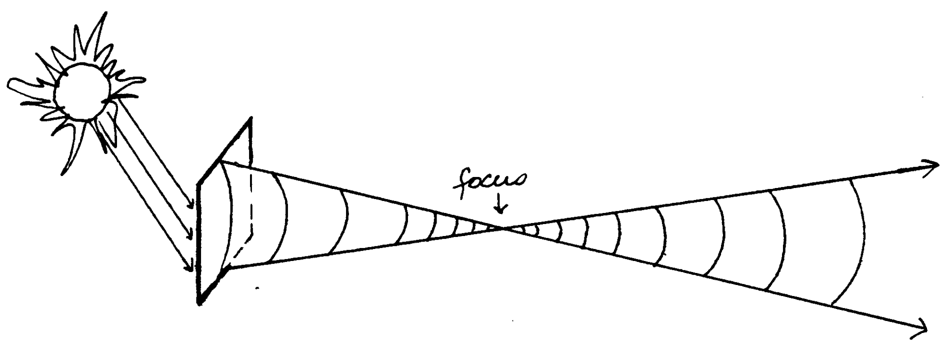


Though the sun appears as a bright point in the sky, the light we receive is collimated or composed of parallel rays of light. Sunlight maintains a consistent plane wave as opposed to the gradually diverging spherical wave.

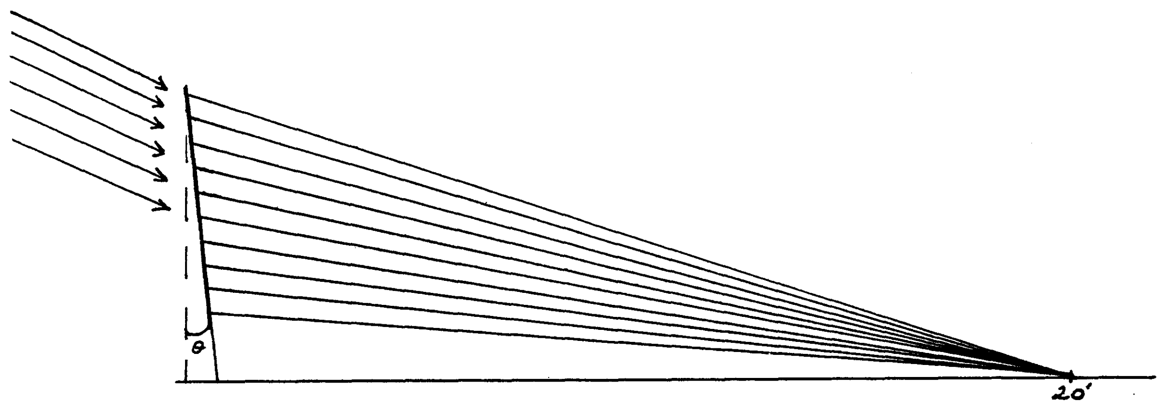
Focalpoint gratings focused colors in space as a result of interfering a collimated beam with a spherical beam:



When lit with the sun's collimated light, the Focalpoint gratings projected a converging beam which focused in space:



If one grating diffracts a continuous spectral sequence, I speculated that a vertical row of ten aligned gratings could diffract the same spectral sequence as a single, large-scale diffraction grating. Theorizing that if the ten vertical gratings were focused in one color at a single point, their individual spectra would diffract at slightly different angles. These angles would vary precisely allowing the colors of one grating to continue into the next grating above or below it. For example, imagine that the first grating at the top of the column is green; the second, right below it, is turquoise; the third, blue; the fourth, purple-magenta; and so on through the ten gratings. Thus, a single spectrum would emanate from the ten aligned plates. The angles of each grating were calculated as a function of the November sun angle and the color focus on the ground twenty feet from the grating surface:



Initially, these angles were determined by the standard grating equation $\sin\theta_r - \sin\theta_i = \frac{\lambda}{d}$. $\sin\theta_r$ is the angle of reference determined by the sun angle and the grating incline; minus $\sin\theta_i$, the angle between the grating height and the color focus, equals λ, the wavelength of light; divided by d, the spatial frequency or density of the resulting relief pattern recorded in the emulsion. Each hologram required incessant testing to ascertain the exact construction angles which would preserve the final spectral order in sequence from plate to plate.

Illuminated by direct sunlight, a row of ten gratings diffracted a single, radiant spectrum which altered as the observer approached. Figure 13 summarizes the colors perceived at the respective distances from an eye height of 63". People of differing heights would see variation of this color sequence. The width of the color bands represent the amount of color coverage on the plate surface when struck with sunlight. The narrow band of color increases from two feet to the point of secondary color focus at nine feet when all of the plates are light turquoise. The brilliance of this color verges on white light. Its sheer intensity severely limits the viewing duration to a few seconds at a time. After the focus, the width of the color seen on the plates gradually decreases as the observer moves away.

The colors appear most vivid at the focus, for the light converges and focuses on the retina, filling one's entire field of vision with light. This generates the perception of colors sparkling in space though they are actually emanating from the plate surface.

During the installation in the Whitaker atrium, the focused spectrum could be seen projected onto the architectural surfaces as a sharply defined spectrum when Focalpoint was directly illuminated. However, several weeks of overcast weather and the unfortunate placement of the Green Building limited the opportunities to see the installation entirely lit with bright sunlight. By mid-December, the sun's altitude had lowered ten degrees, considerably altering the angles of diffraction. Originally intended to diffract the higher order colors straight forward, the lower sun angle projected one of the higher orders up to the first balcony while the alternate reflected off the floor in front of the sculpture; the primary spectrum, originally focused to the floor, projected straight forward.

LAMINATION

Many optical laminates are available, but few remain clear after curing which is essential for holographic applications. I tested three commercial products to determine which best withstood extensive contact with moisture and sunlight. Norland Optical Cement #61, a one-step adhesive, gradually darkened the emulsion surface, a reaction known as 'print-out.' Epo-Tek #302-3 from Epoxy Technology, Inc., remained clear but the two-part epoxy was inconvenient and slow curing. Uvex #525A from Uvex, Inc., remained clear and cured rapidly. However, this material is an irritant requiring ventilation and extreme care to limit skin contact.

The lamination of thirty glass holograms to a 1/4" panel of 96" x 34" safety glass required three procedures: the thorough cleaning of the glass; application of the laminate; and curing with a mercury vapor lamp which emits ultraviolet light. The safety glass lay on the floor and was cleaned completely with methanol and then each area was recleaned with methanol and ethyl alcohol prior to laminating (fig. 14). The actual lamination process involved covering the hologram with the clear laminate, heating the plate slightly to decrease the viscosity of the optical cement, placing the inverted plate in position, and gradually lowering the plate to avoid trapping air bubbles. The laminate set under a few seconds of ultraviolet light and cured after several minutes. However, the mercury vapor lamp available lacked sufficient intensity to cure the laminate when the beam was diverged to cover the entire plate. This extended the curing time. I hand-held the lamp during the initial setting and then cured each plate for one half hour illuminated by the diverged beam. Some shrinkage occurred during curing, possibly resulting from the thin laminate pulling out of the deeper grooves in the emulsion surface or the increased setting time. The laminated holograms were unaffected by moisture during the installation. Two plates darkened slightly from print-out, possibly stemming from a weak bleaching solution and not the laminate.

The permanent lamination of holographic emulsion surfaces is meticulous and tedious especially on a large scale. Other approaches to the large-scale production of holograms include mastering and embossed printing on plastic, and photo-etching using a photo resist and metalizing process. Both methods are most successful with reflection holograms. The diffraction efficiency of printed transmission holograms is substantially lower. However, holographic printing is the most feasible approach to the large-scale application of holography. The holographic emulsion surface is too sensitive to weather fluctuations, surface damage, or potential disintegration from extensive exposure to sunlight to survive in permanent, public settings. Plastic substitutes with high diffraction efficiency would increase holographic design potentials for environmental installations.

GLASS PIPES

The glass pipes fulfilled dual optical and conduit functions. When the row of ten 10' x 2" diameter glass pipes were filled with water, they focused sunlight into a series of narrow strips like long, cylindrical lenses. The focused stripe of light advanced across each pipe surface enabling the viewer to see it regardless of position. These lines of light illuminated the Focalpoint gratings and increased their viewing angle to the width of the atrium. Observers could walk from side to side across the space watching the bands of colors move with them. Without the pipes, the observer would have seen the diffracted colors standing directly in line with the sun only. The staggered spacing between the pipes produced a progression of thick and thin lines of light unifying the gratings into a single panel of colored bands which varied in intensity as the observer moved (fig. 15).

The base of each pipe fit onto rubber stoppers drilled to admit water from the pump and manifold (fig. 16). At the top of the sculpture, the pipes lay into an aluminum harness, lined with rubber and welded to the support frame. Water was pumped up the pipes, filled a trough, and overflowed as a single sheet that cascaded down the front surface of the glass panel. The falling water created undulating patterns catching highlights of color in the rippled surface. The light and shadow of the pipes across the gratings formed holographic-like reflected color images over the water in the reservoir. The colors and illusions were continually changing as the sunlight shifted across the glass and grating surfaces (fig. 17).

STRUCTURAL SUPPORTS, BASE, AND PUMP AND MANIFOLD SYSTEMS

The substantial weight of the water-filled pipes required an additional tubular aluminum frame for structural support. Another aluminum frame supported the glass-grating panel at a slight incline to generate the proper water flow. These supporting frames joined at the top, formed a lean-to structure, and connected the pipe harness and water trough. The trough, filled by the ten pipes, was siliconed to the glass panel preventing water from flowing down the back surface of the glass and over the laminated gratings (fig. 18). The aluminum structural supports bolted to the false bottom of the wooden base. The false bottom concealed the pump and manifold. The base measured 4' x 8', was constructed from coated plyboard, and sealed with rubber silicone. The base reservoir, structural supports, harness and trough were painted a medium gray while the exterior of the base was painted white (fig. 19).

Focalpoint had a recirculating water system which maintained 3" of water in the reservoir at all times. The water drained from the reservoir into the pump-manifold system below. The water flowed through a water filter and then to the pump. The half horsepower pump employed was too powerful. To decrease the pressure and flow, a portion of the water recirculated through the pump. Regulated by a valve, this controlled the final sheeting effect down the glass panel. The water was pumped into the manifold which distributed it to the ten glass pipes supported above. The entire pumping and manifold system was connected with radiator hose segments and clamps constituting the complex appearance of an economical system (fig. 20).

A wetting solution additive reduced the water's surface tension causing it to flow evenly down the glass surface. Originally a commercial product, Jet-Dry, was used, but it encouraged the rapid growth of algae. Chlorine was added to kill the algae, but led to further discoloration of the water from chemical reactions with metal components in the pumping system. The installation was repeatedly drained and filled until a neutral wetting solution and a small amount of pool algecide limited the algae growth. These chemicals plus the water filter maintained clear water for a week.

Further installations of Focalpoint would require rebuilding portions of the base, pump and manifold systems. The weight and backward thrust of the water-filled pipes splayed the back corner joints. I recaulked all of the base seams as a precaution after Focalpoint had been installed a month. The proper pump and non-corrosive manifold system would simplify maintenance and control the water flow and algae growth more efficiently.

From the onset, Focalpoint was experimental. The complications entailed in exploring and realizing this installation were substantial and far beyond the scope of my previous experience. I requested and received technical assistance from many to whom I am extremely grateful. Certain aspects of the project materialized due to exceptional assistance from: Shaoul Ezekiel for his holographic expertise; Tony Seivers for the initial design of the trough and pipe supports; and W.B., Inc., the Boston firm responsible for the final design and fabrication of the fountain's base, support frames, trough and manifold systems.

FOCALPOINT AT THE WHITAKER

The Whitaker Medical Science Building at MIT was designed by Mitchell Giurgola. The atrium is a narrow, lofty space with wall fenestration on east and west facades, and a triangular skylight extending its length. An open staircase spirals up through the atrium connecting the balconies of the second, third, and fourth floors. The walls are painted white with muted pastel detailing that varies in color by floor. The space is tall, light, unadorned and used primarily as a corridor between Kendall Square and the MIT campus.

Simple components constituted Focalpoint's sculptural design. From the front, the viewer was confronted by a tall rectangle consisting of colored areas divided vertically and set into a white rectangular base (fig. 21). From the side, glass cylinders met the rectangular glass panel at the apex. From the back, or view seen entering the atrium's west entrance, one saw a tall rectangular shape composed of a row of glass cylinders, set into a white base. From above, Focalpoint appeared as a triangle composed of two glass planes, one flat and the other undulating, placed in a gray rectangle. Focalpoint's structure was as minimal as the atrium's architectural elements. The gray panel and pipe supports seemed to disappear when seen against the west wall fenestration. The rectangular gratings were miniature reminders of the huge glass panels spanning the east and west walls. Circular, rectangular and triangular shapes were integral to both the sculpture and its environment.

Color further integrated the installation with the architecture. Under direct sunlight, the focused spectrum was cast onto architectural surfaces and migrated across them with the sun's progresion. The vivid color seen throughout the atrium encouraged observers to linger in a space through which they usually hurried. The pastel colors seen as a result of indirect lighting complemented the simplicity of the atrium and the chosen tones of the architectural detailing. The pastel colors were visible from Hayward Street, a block away from the eastern entrance to the Whitaker atrium on Carleton Street.

Focalpoint combined light and water in an environmental installation. The sound of falling water emanated faintly throughout the entire atrium. People touched the water surface as it flowed down the glass. They stopped more frequently when the water was flowing as if the patterns of the water's movement could not be fully grasped if the observer was also in motion. By focusing on the water patterns, the eye raced up and down the surface creating a slight sense of vertigo. Ignoring the water movement, the eye focused on the colors of the vertical bands of light. Closer viewing distinguished slight color reflections behind the plates hovering in space. The light changed the installation and those changes intrigued people.

Though the design for the water fountain developed from technical limitations of holography, Focalpoint was intended to create a mood which encouraged the observer to recognize the subtle totality of an environment. Absorbed by color, the observer might experience a momentary sense of timelessness. I wanted the observer to respond to the color transitions by becoming aware of the entire environment and the sun's influence upon it. The Whitaker atrium completed Focalpoint by synthesizing installation and environment such that one heightened the other to the benefit of the whole.

III. ILLUSTRATIONS

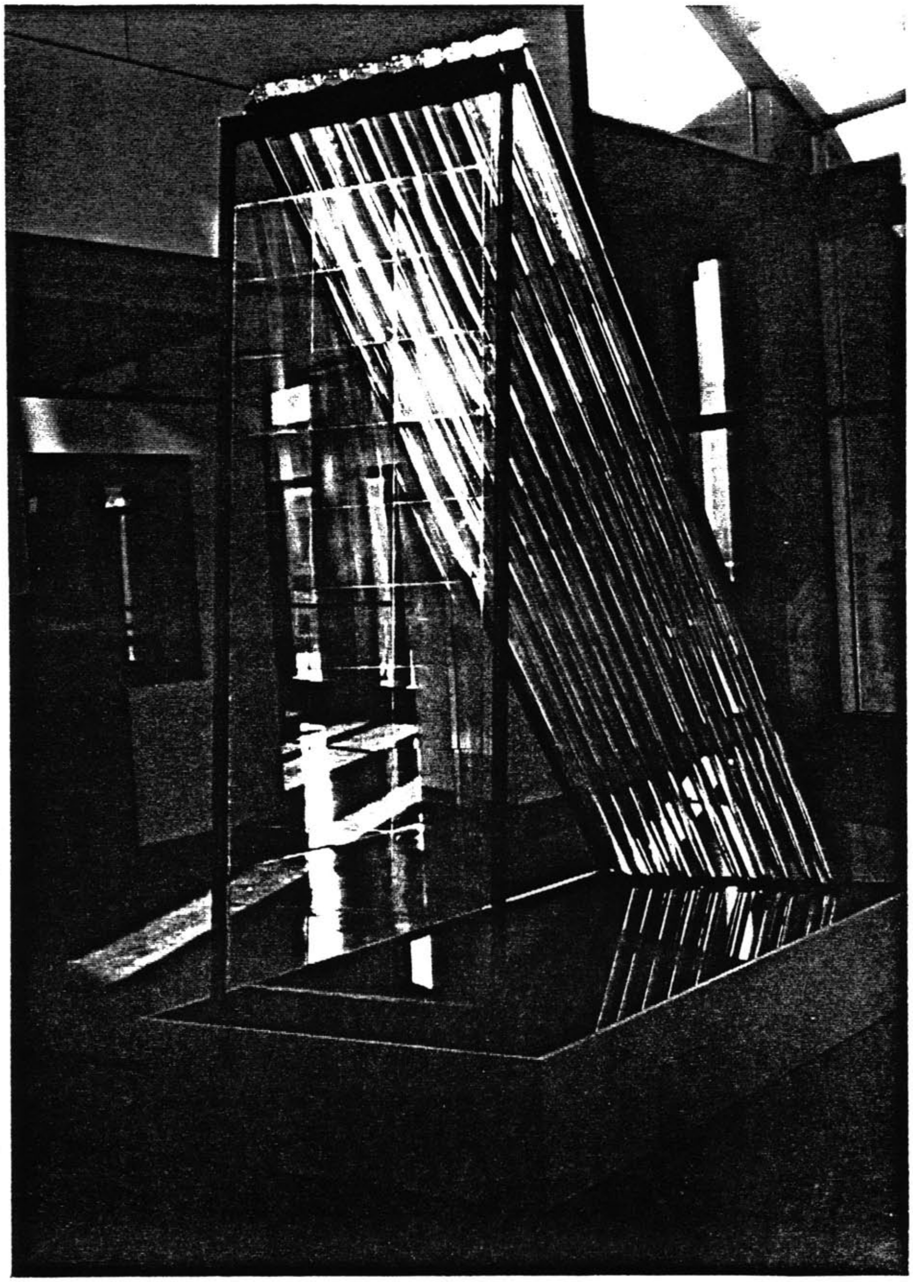


fig. 11 Focalpoint installed in the Whitaker Medical Sciences Building, MIT (photo: Mark Strand)

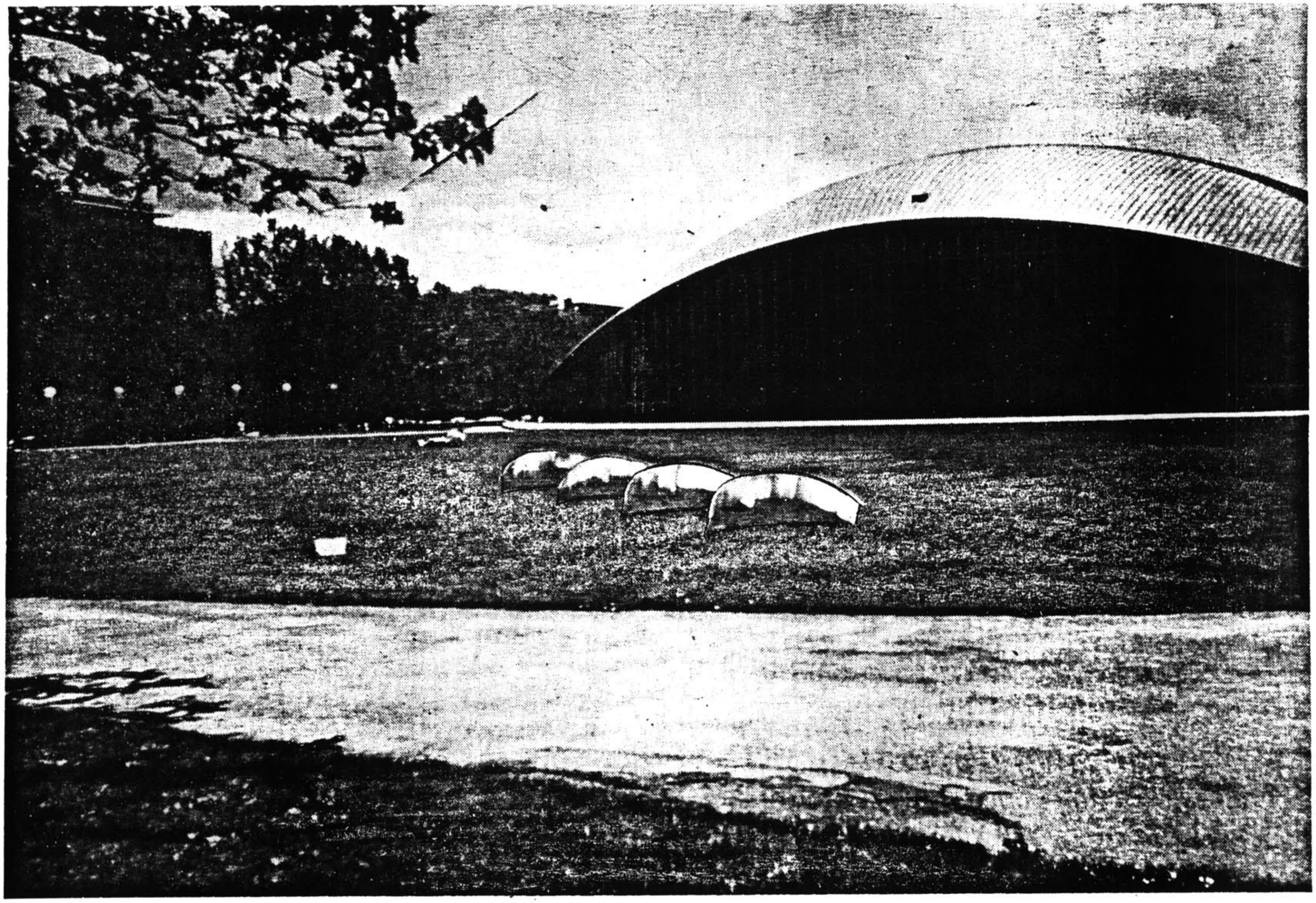


fig. 12 Lightscape installed on Kresge Lawn, MIT
(photo: S.N. Weber)

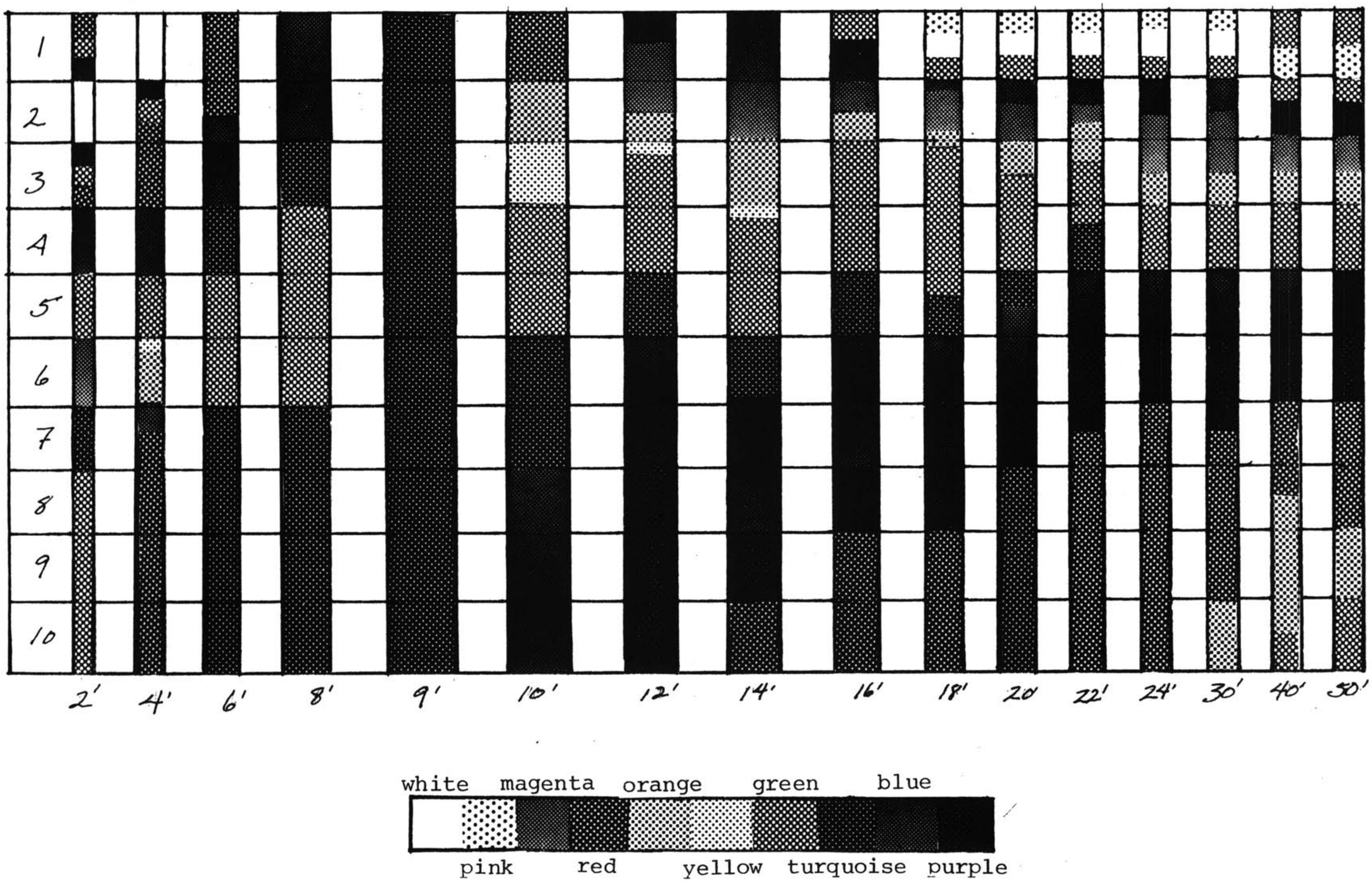


fig. 13 Color progression of <u>Focalpoint</u> seen from an eye height of 63"

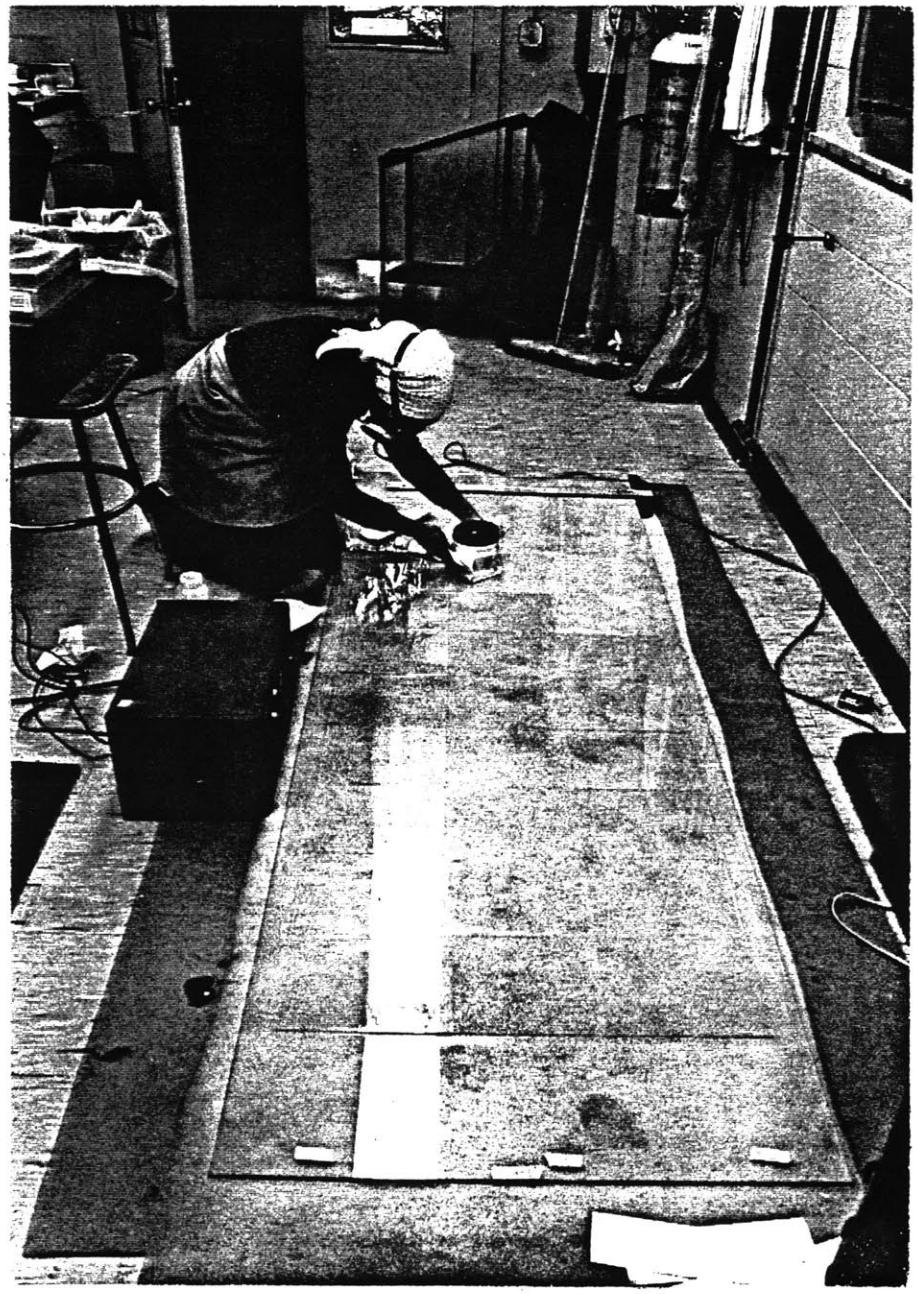


fig. 14 Cleaning glass panel during lamination of holographic plates.
(photo: Beth Galston)

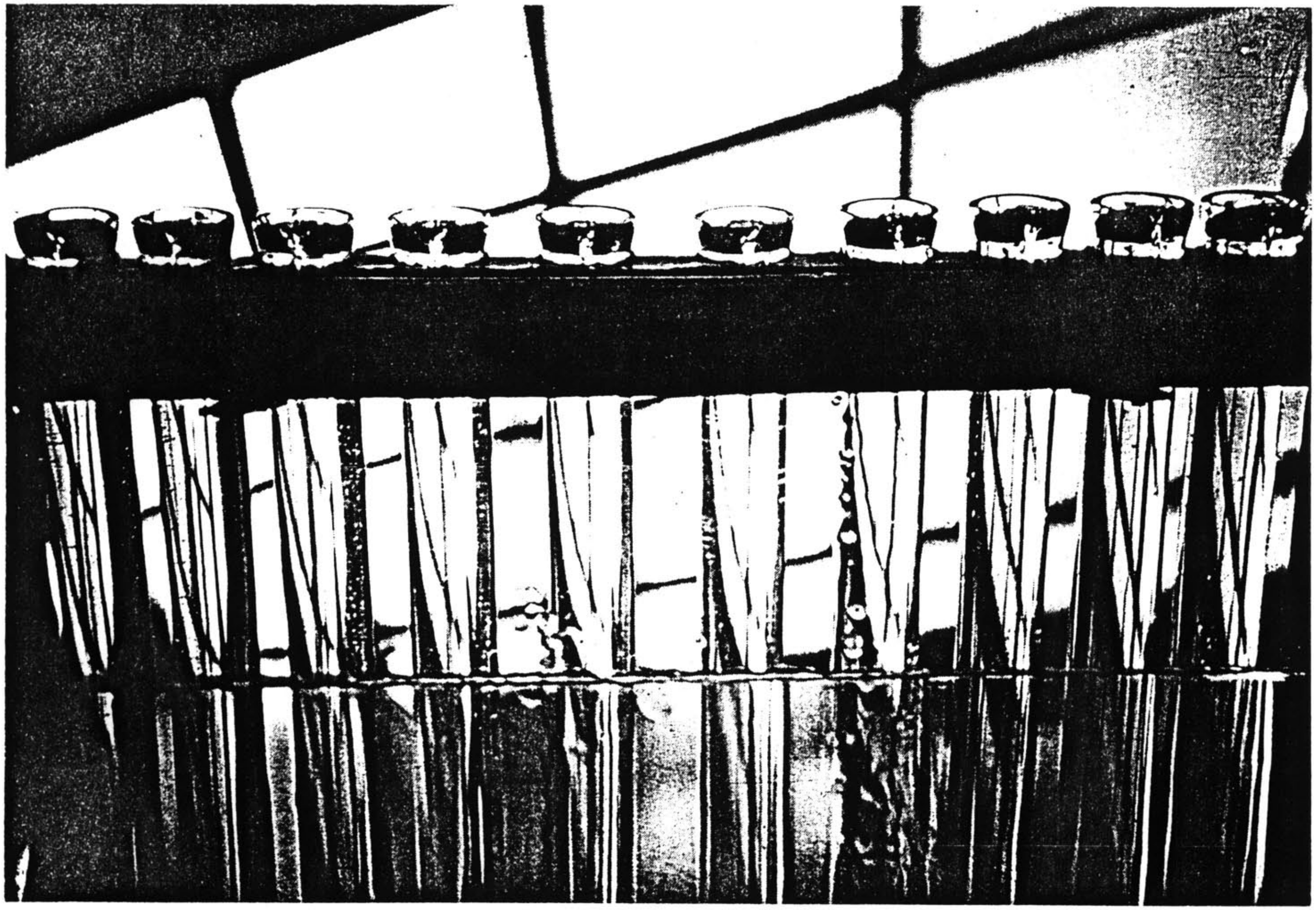


fig. 15 Staggered spacing between glass pipes
(photo: Bruno de Lar)

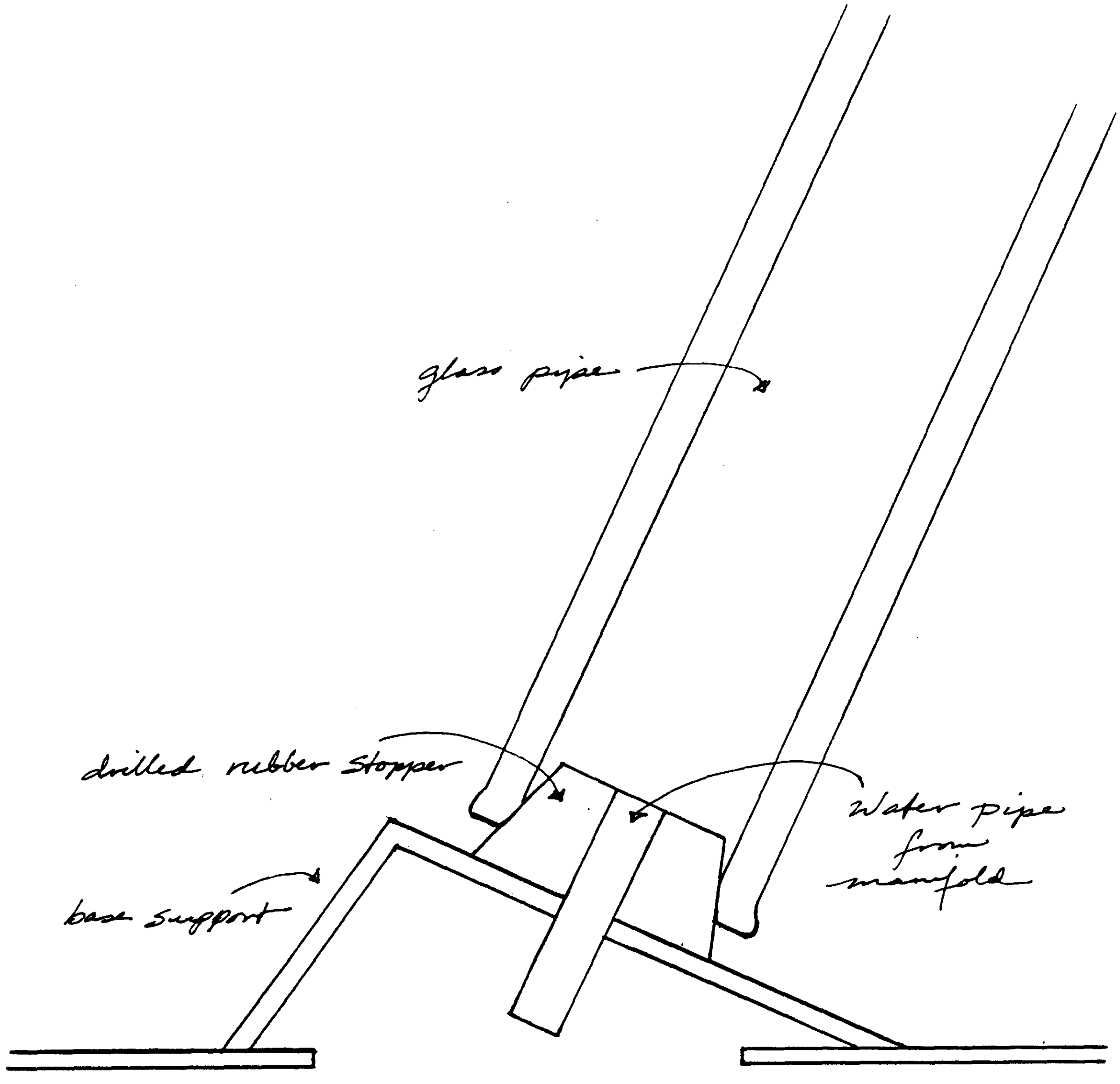


fig. 16 Detail of glass pipe supports

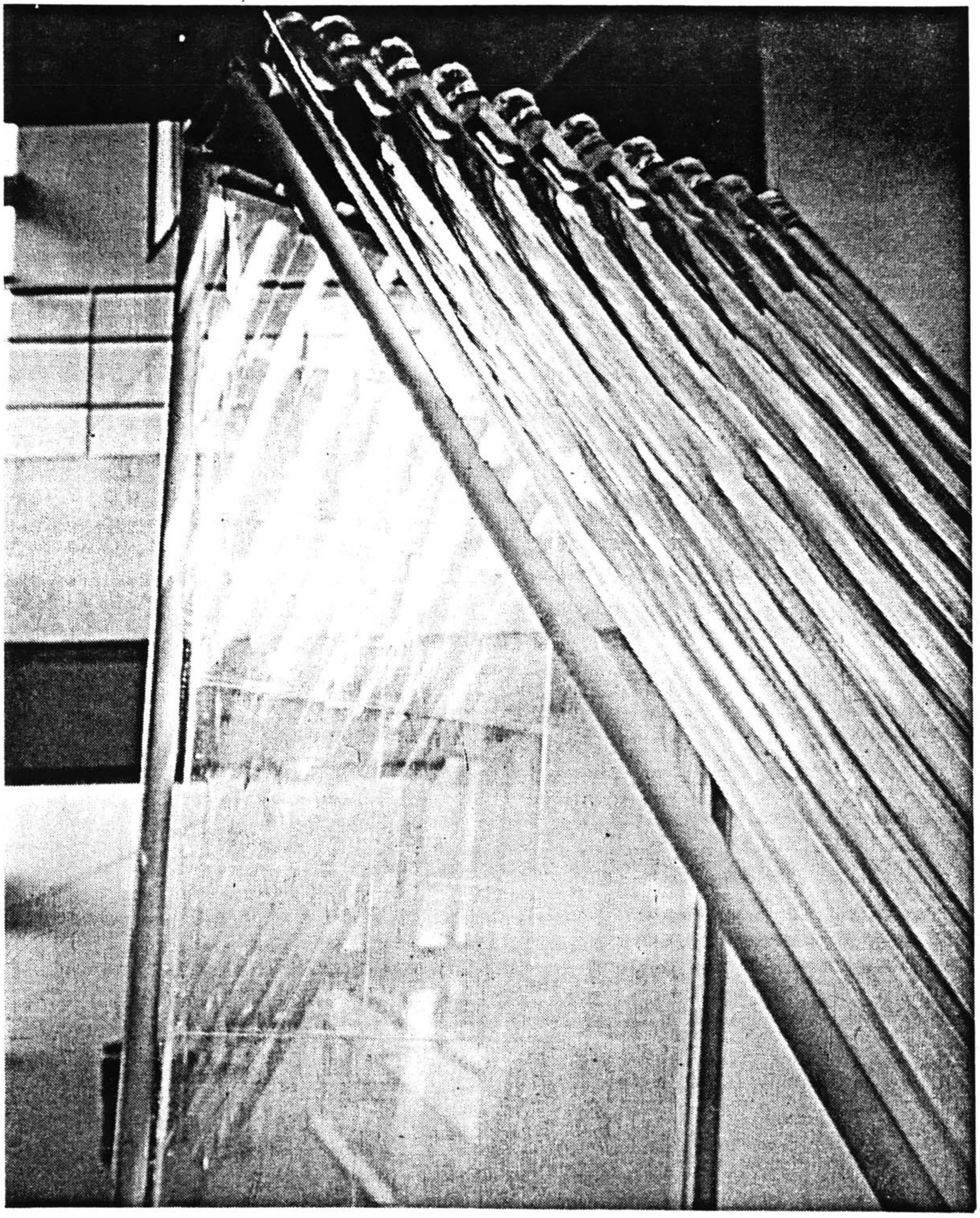


fig. 17 Reflected images of glass pipes on grating-glass panel (photo: S.N. Weber)

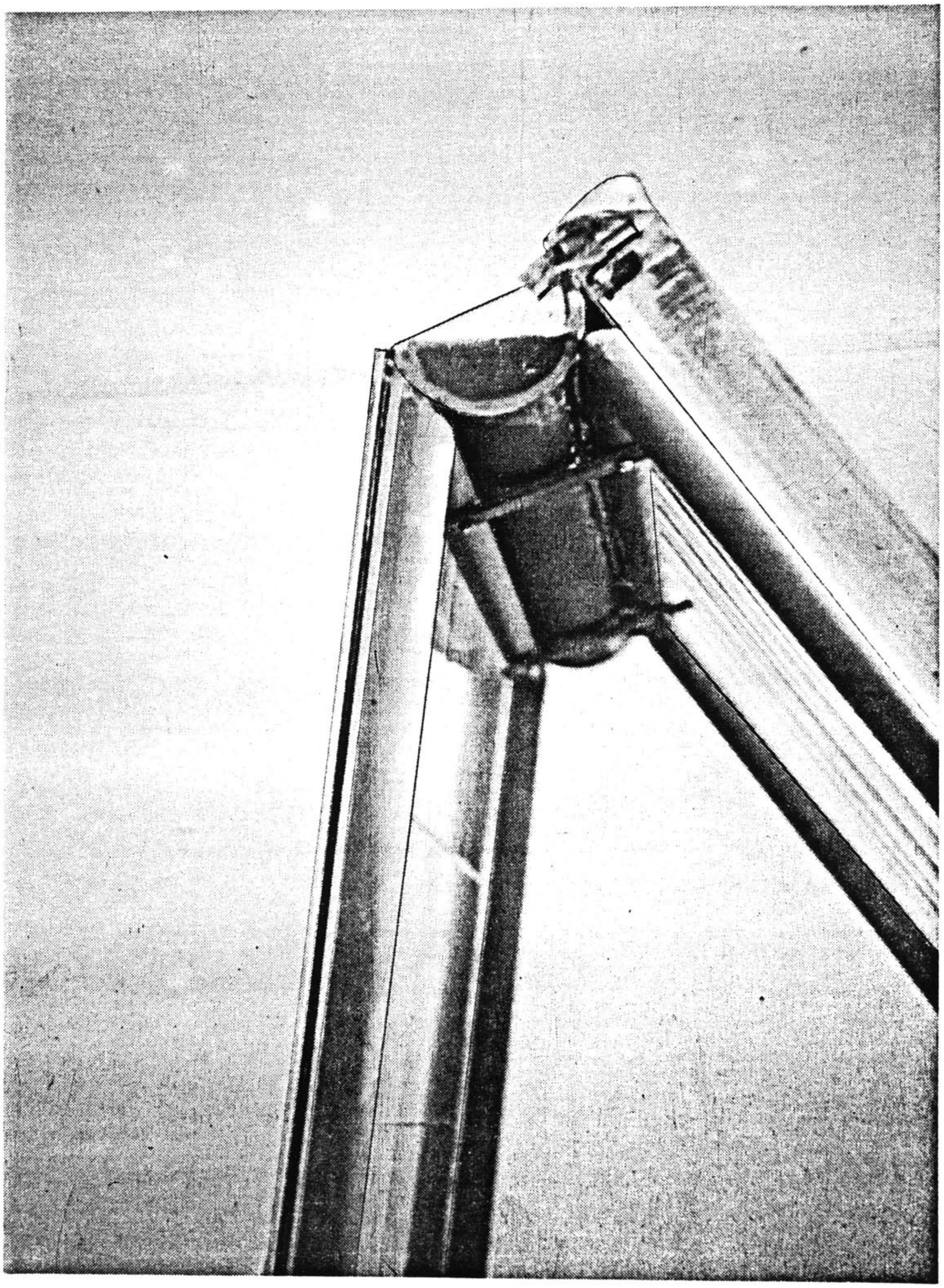


fig. 18 Detail of pipe harness and trough system
(photo: Bruno de Lar)

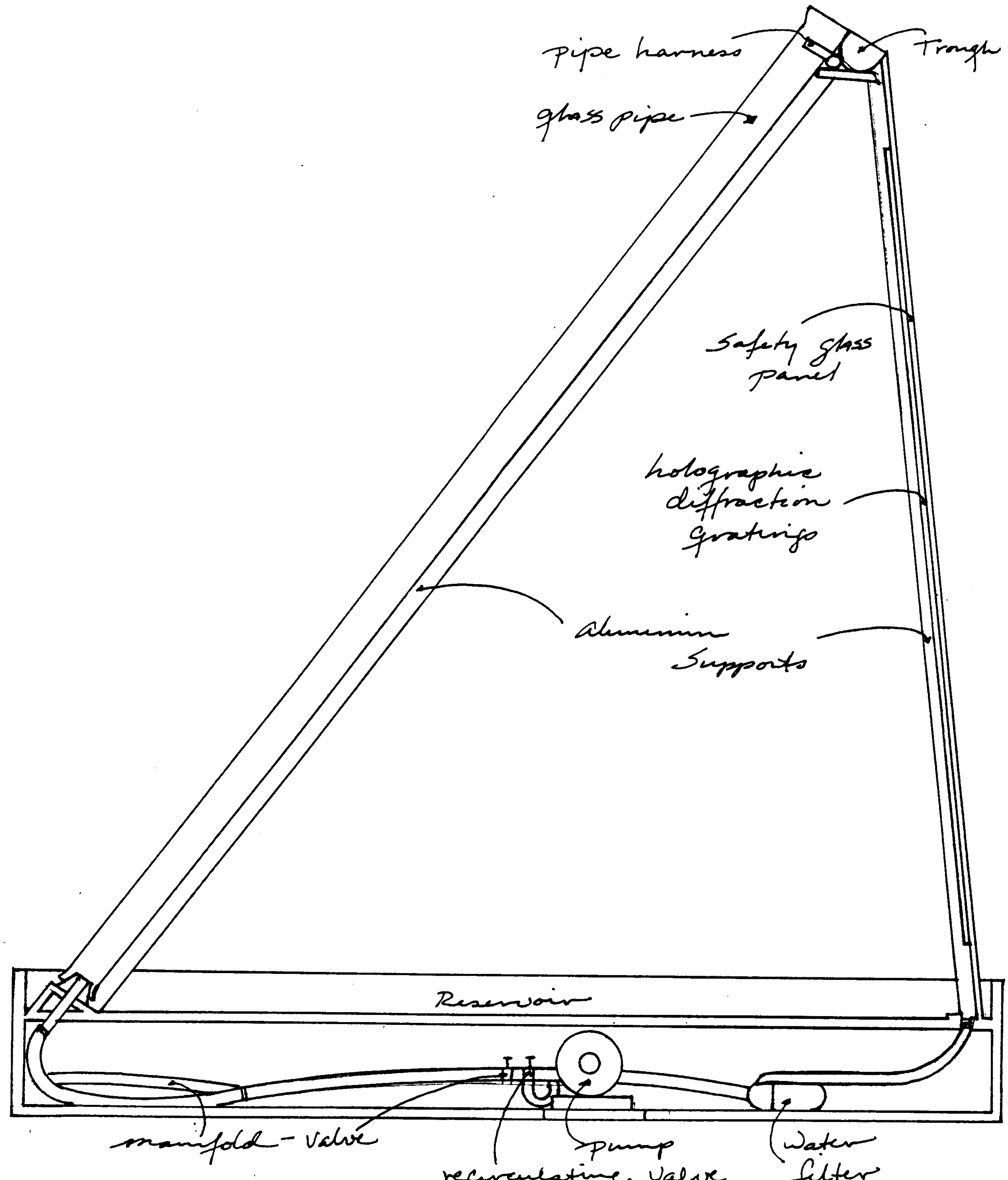


fig. 19 Section of Focalpoint

Scale: 3/4" = 1'-0"

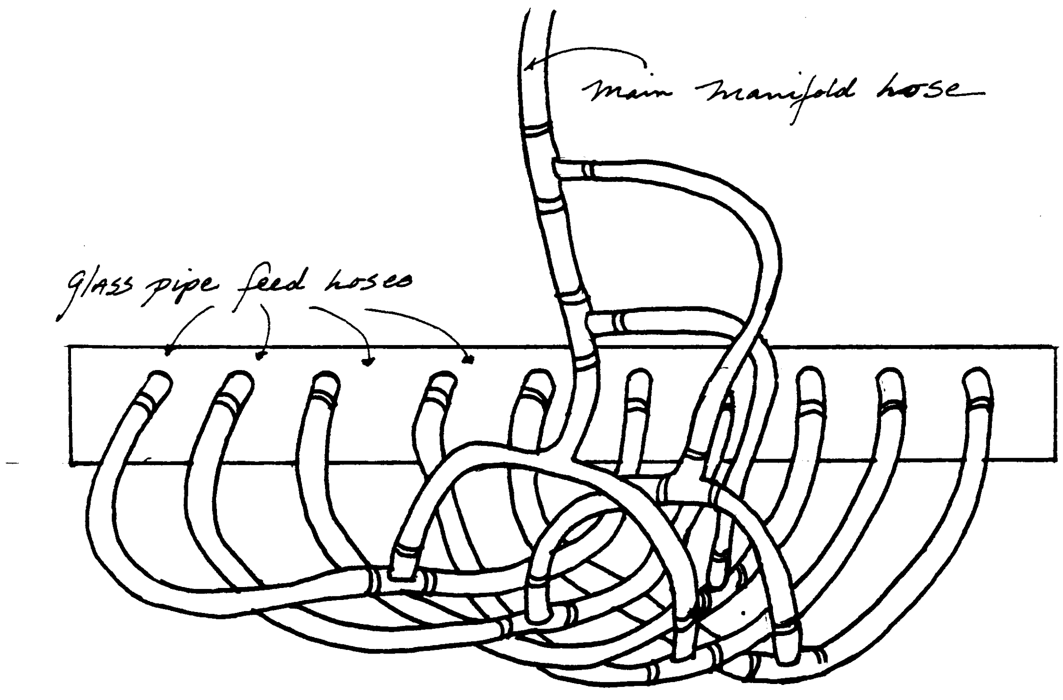


fig. 20 Manifold System

fig. 21 Focalpoint seen from the east entrance of the Whitaker atrium
(photo: S.N. Weber)

IV. ENVIRONMENTAL HOLOGRAPHY

"There is a unity in the
universe and a unity in our
own experience."

(Joseph Campbell)

Working with sunlight is environmental design. All aspects of the sun's movement and its effect on the environment must be considered. Robert Irwin stated in a recent article that "art existed not in objects but in a way of seeing."[17] Often a piece might exist in the natural environment already. The artist's "gesture" in that place, sensitive to its potentials, would only heighten or draw attention to "what was already there."[18] Irwin suggests that art is an attitude; an approach towards seeing an environment, appreciating its inherent properties, and then considering what alternatives would magnify these qualities improving one's impression of the environment as a whole. Irwin's projects reflect this basic and direct approach. They employ materials in a straightforward manner and on a scale which heightens the observer's awareness of the surroundings. By deriving inspiration from both the environment and the individual's sensibilities, environmental art incorporates only the essential elements necessary to distinguish the place as an artwork.

Antoni Tapiés said "reality is relative to our degree of understanding and that it is by using the most humble means that we can begin to perceive deeper interpretations of the truth."[19]

Light is basic. As the most elementary impression, it defines surfaces and forms thus delineating our world.

James Turrell creates light-tangible environments where the "light resides in space rather than on the wall."[20] The light has a mist-like quality, suspended in air, pulling the viewer towards it. Turrell's installations create the illusion of dawn or dusk when the particles of light seem to float and are as difficult to focus as laser speckle. Regarding his light installations, Turrell states that "the light draws attention only to what it is."[21] No metaphoric content is implied; rather, he acknowledges light as a material with particular attributes which attract us. Light provokes mood and captures us by its presence.

Pure color is derived from light. The sheer beauty and intensity of color affects us viscerally on first impact, non-intellectually, leaving us for a moment wordless, before we decipher the experience. Ogotemmêli, a Dogon elder, recounted sacred tribal cosmology to French anthropologist Marcel Griaule. He explained that "the Word is the most important thing in the world."[22] Words differentiate impressions and create by specifying the particular. Preceding this principle of differentiation, is the intangible, the undifferentiated experience; like the impression that remains from a dream that slipped away. We know the feeling but lack the words to recapture it. Absorbed by a sensation, we experience a brief sense of timelessness. Words soon define the experience, yet, during those first seconds, time is lost to a semi-meditative state. Light and color can inspire us to this silent appreciation and an increased awareness of our surroundings.

Focalpoint used holography to compose with pure color. The impact of color in an environment suggests both architectural and solar energy design potentials. Last summer I proposed a large-scale project to cover the windows of Lobby 7 at MIT with holographic diffraction gratings. These gratings would focus the afternoon sunlight into a spectrum across the dome. As the sun descended, the spectrum would cross the dome and align with the central corridor at sunset. The line of colored light was intended to create an interior sundial. The light's movement would attract attention to the dome and the sun's effect on it. Color would traverse architectural forms during the day or be diffracted by artificial lighting at night.

Besides projecting light to unlit areas in the architectural environment, holography could focus specific colors on solar energy cells. Recent solar research maintains that focused holographic gratings have increased the energy production of solar cells. Some semi-conductors in solar cells are more receptive to certain wavelengths of light. Holographic gratings can diffract and focus the proper wavelengths on these components increasing their efficiency.[23] The combined architectural and energy design potentials of holographic materials is an unexplored field. Holographic diffraction grating focused for solar energy could alter architectural design by demanding maximum southern exposure and daylighting in buildings while utilizing the design possibilities of color and light.

The permanence of holographic materials is the major obstruction to extensive environmental use. However, methods to manufacture plastic gratings including embossing and photo-resist techniques are possible alternatives. Cash registers now include holographic diffraction grating elements and the computer industry is researching the potential use of holography for memory storage. This implies an expanding interest in holographic applications. The movement of color through an environment is only one aspect, yet it suggests a means to increase the awareness and use of sunlight as a design and energy tool in our future environments.

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FOOTNOTES

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6. Cornell, p. 134.

7. Ibid., p. 155.

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9. Graham Chedd, "Chaco," program in Odyssey series aired on WGBH-TV (Boston), October 5, 1982.

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11. J.H. Jongkees, Studies on Old St. Peter's (Groningen: J.B. Wolters, 1966), p. 37.

12. Ibid., pp. 38-39.

13. Ibid.

14. Robert Branner, Chartres Cathedral (London: Thames and Hudson, 1969), p. 107.

15. Henry Adams, "Twelfth Century Glass," in Chartres Cathedral, Robert Branner, ed., p. 236.

16. Hans Jantzen, High Gothic, James Palmer, trans. (New York: Pantheon Books, 1962), p. 69.

17. Quoted in "Profiles--Robert Irwin," by Lawrence Wechler, The New Yorker, Part I, March 8, 1982, p. 89.

18. Ibid.

19. Rowland Penrose, Tapiés (New York: Rizzoli International Publications, 1978), p. 177.

20. Quoted in "'Batten' by James Turrell Opens at Hayden Jan. 22," Tech Talk, January 12, 1982; vol. 23, #21, p. 4.

21. Ibid.

22. Marcel Griaule, Conversations with Ogotemmêli (Oxford: Oxford University Press, 1972), p. 59.

23. W.H. Bloss, M. Griesinger and E.R. Reinhardt, "Dispersive Concentrating Systems Based on Transmission Phase Holograms for Solar Applications," Applied Optics, vol. 21, #20 (October 15, 1982), p. 3739.

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II. Temporal and Transient Sunlighting

fig. 1 Hawkins, Beyond Stonehenge, p. 201.

fig. 2 Ibid., p. 195.

fig. 3A Cornell, Stargazers, p. 98.

3B Krupp, Ancient Astronomies, p. 228.

fig. 4A Cornell, Stargazers, p. 99.

4B Ibid., p. 101.

fig. 5A Krupp, Ancient Astronomies, p. 188.

5B Ibid., p. 186.

fig. 6 Cornell, Stargazers, p. 156.

fig. 7A Steen Eiler Rasmussen, Experiencing Architecture (Cambridge, MA: MIT Press, 1980), p. 228.

7B Ibid., p. 229.

fig. 8 Jocelyn Toynbee and J.W. Perkins, The Shrine of St. Peter and the Vatican Excavations (New York: Longmans, Green and Co., 1956), p.5.

fig. 9 Herbert von Einem, Michelangelo, Ronald Taylor, trans. (London: Methlen and Co, Ltd., 1973), plate XXVI.

fig. 10 Christian F. Otto, Space into Light (Cambridge, MA: MIT Press, 1979), p. 20.

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